

# **Interagency Committee on the Health Effects of Non-ionising Fields**

Report to Ministers 2018

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# Executive summary

The Ministry of Health convenes a technical advisory committee, the Interagency Committee on the Health Effects of Non-ionising Fields (the Committee), to monitor and review research on the health effects of electromagnetic fields. The Committee reports to the Director-General of Health but also periodically prepares a report for the Ministers of Health, Environment and Business, Innovation and Employment to provide them with background information and a current summary of key research findings.

This report is not intended to be an exhaustive or systematic review of recent research. Rather, it highlights key findings from comprehensive reviews undertaken in recent years by national and international health and scientific bodies, illustrated in places by examples from individual studies of interest or that exemplify work carried out in particular areas.

This 2018 publication updates the report published in 2015, including more recent information where it is relevant. The conclusions, however, remain unchanged.

## Extremely low frequency magnetic fields

The questions over whether exposures to extremely low frequency (ELF) magnetic fields have any effect on the development of leukaemia in children, and neurodegenerative diseases in adults (such as Alzheimer's disease and amyotrophic lateral sclerosis), remain unresolved. Further studies on childhood leukaemia have not led to any more definitive conclusions on whether the associations between long-term exposure to ELF magnetic fields and childhood leukaemia show a true cause-and-effect relationship or are simply the results of biases (acknowledged as a possibility), confounding by unidentified factors (less likely) or something else.

This work has confirmed, however, that even if magnetic fields have some effect, this would be responsible for only a very low percentage of childhood leukaemias. A comprehensive review by the World Health Organization (WHO) published in 2007 recommended the use of exposure guidelines such as those used in New Zealand, together with very-low-cost measures to reduce exposures where this can be readily achieved. The Committee and the Ministry of Health support these recommendations.

# Radiofrequency fields

Research into the possible effects of radiofrequency (RF) fields on health also has some open questions. Although studies into brain tumour risks associated with mobile phone use have found a small association in the heaviest users, the researchers acknowledge that this could simply reflect biases in the data. Nevertheless, the suggestion that there may be a risk has meant that the International Agency for Research on Cancer (IARC) classified RF fields as a 2B 'possible' carcinogen in 2011.<sup>1</sup>

Animal studies do not suggest an effect of RF fields on cancer. Analysis of brain tumour registrations in relation to numbers of mobile phone subscriptions does not show any trends suggesting a link, but this could be due to long latencies or (more improbably) some other factor that is simultaneously acting to reduce brain tumours. Research published since the IARC classification tends to weigh against the possibility of any risk, but may just reflect the fact that exposures from the newer mobile phone technologies are much lower than those in use at the time most of the data used in the IARC evaluation was acquired.

RF research is continuing in a number of areas, but data currently available provides no clear or persuasive evidence of any other effects. For this reason, the Committee and the Ministry of Health continue to support the use of exposure limits for RF fields set in the current New Zealand Standard, which is based on guidelines published by an international scientific body recognised by the WHO for its independence and expertise in this area. Those guidelines were first published in 1998 and endorsed, following a review of more recent research, in 2009 and 2017. A draft revision of the guidelines has been published recently, but has a very similar basis and shape to the 1998 version.

The Committee notes, however, that recent data suggests that at some frequencies the margin of safety may not be quite as high as previously thought. This is not of immediate concern, as public exposures are normally, at most, only small fractions of the allowable limit and a considerable safety margin remains. However, the Committee recommends reviewing the situation following publication of the revised international guidelines and a WHO evaluation of RF fields and health. When these documents will be published is not yet known, but it may occur in 2019.

## Overall conclusions

The findings of recent research do not cause the Committee to consider that current policies and recommendations should be changed.

In view of the continuing public interest in this area, the ubiquitous nature of exposures and the open research questions that remain, the Committee will continue to monitor new research.

<sup>1</sup> As noted in the 2004 *Report to Ministers*, IARC classified ELF fields as 2B in 2002.

# 1 Introduction

The Interagency Committee on the Health Effects of Non-ionising Fields (the Committee) was originally established in 1989 by the then Ministry of Economic Development to monitor and review research on the health effects of extremely low frequency electric and magnetic fields. The scope was extended to include radiofrequency fields in 2001, at which time it became a Ministry of Health technical advisory committee. The current terms of reference and Committee membership are presented in Appendix F.

Extremely low frequency (ELF) electric and magnetic fields are found around any wires or equipment that carries mains electricity. This includes the high-voltage lines and substations that form the national electricity transmission network, the lower-voltage lines, substations and transformers that distribute electricity locally, and wiring and electrical appliances in the home.

ELF electric fields are produced by the voltage on a wire or appliance connected to mains electricity. Electric fields are easily shielded and, for example, the electric fields inside a house with high-voltage power lines running overhead are similar to those in any other house.

ELF magnetic fields are produced by the electric current flowing through a wire or appliance, and in many respects are very similar to the magnetic field around a magnet. (In fact, moving a magnet produces an ELF magnetic field.) Magnetic fields are not easily shielded, but around most appliances and electrical infrastructure the strength of the field decreases quite quickly as you move further away.

Radiofrequency (RF) fields make up the radio waves produced by radio and television transmitters. This includes broadcast transmitters used to transmit AM and FM radio and television programmes, the equipment used for mobile radio, mobile phones and mobile phone base stations, and devices that communicate using WiFi.

While ELF and RF fields are both electromagnetic, their physical properties and the way they interact with the body differ in some important ways.<sup>2</sup> RF fields carry energy away from the transmitter, whereas ELF electric and magnetic fields are fixed in place around whatever produces them. While the body is an electrical conductor, the electrical properties vary markedly between extremely low frequencies and radiofrequencies, which is why the way ELF and RF fields interact with the body is also different.

For some background material on ELF and RF fields, see Appendix G. Further information is also available on the Ministry of Health's website.<sup>3</sup>

<sup>2</sup> Light is also electromagnetic in origin, but it has quite different properties to ELF and RF fields.

<sup>3</sup> [www.health.govt.nz/our-work/radiation-safety/non-ionising-radiation](http://www.health.govt.nz/our-work/radiation-safety/non-ionising-radiation)

A key function of the Committee is to review recent research findings, especially recent research reviews published by national and international health and scientific bodies, to determine whether it should recommend any changes to current policies. Periodically the Committee prepares a report for the Ministers of Health, Environment and Business, Innovation and Employment; the most recent before this report was published in 2015 (Interagency Committee on the Health Effects of Non-ionising Fields 2015).

The Committee considers that the fundamental basis for exposure limits currently recommended in New Zealand is still valid. The purpose of this report is to provide Ministers with the background to the reasoning behind that conclusion and update the 2015 report.

This report is not a systematic review of the research. A steady stream of such reviews comes from expert panels appointed by health agencies in other countries, and by international bodies such as the World Health Organization (WHO) and the European Union's Scientific Committee on Health, Environmental and Emerging Risks.<sup>4</sup> Rather than taking that approach, this report to Ministers summarises the principal findings of these overseas reviews, concentrating on those published within the past six years but also referring back to important older publications that are still valid (eg, the WHO's 2007 review of ELF fields). Some key individual scientific papers are also discussed where they help to illustrate the research and the types of approach being followed to improve our knowledge. The cut-off date for research and reviews included in this report was 7 September 2018.

This report also discusses how the issues are handled in New Zealand, and topics of particular interest that have arisen recently.

<sup>4</sup> Previously called the Scientific Committee on Emerging and Newly Identified Health Risks.

# 2 Current Ministry of Health policies and recommendations in New Zealand

## 2.1 Extremely low frequency fields

The Ministry of Health (the Ministry) recommends the use of guidelines published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP 2010) to manage public exposures to ELF fields. WorkSafe recommends using them for occupational exposures. ICNIRP is an independent scientific body, recognised by the WHO for its independence and expertise in this area. Its guidelines are based on a careful examination of the research data on the health effects of exposure to ELF fields, and include margins for safety.

ICNIRP periodically reviews its guidelines to take account of new research data. The most recent revision was published in December 2010 (replacing previous guidelines prepared in 1998) and is largely based on the WHO (2007) review (see Section 3.2). The essential biological basis for the guidelines has remained unchanged for more than 20 years.

It is well known and understood that ELF electric and magnetic fields induce internal electric fields and currents in the body. If the external fields are strong enough, these induced internal electric fields can interfere with the body's nervous system. The ICNIRP guidelines set **basic restrictions** on the electric fields induced in the body by low-frequency magnetic and electric fields in order to prevent such interference.

Induced electric fields are difficult to measure, so the guidelines also prescribe **reference levels** in terms of the external magnetic flux density and electric field strength, which can be measured easily. Compliance with the reference levels ensures compliance with the basic restrictions, and in most applications the reference levels can be considered to be the 'exposure limits' (although this term is not used as such).

If exposures exceed the reference levels, this does not necessarily mean the basic restriction is also exceeded. However, a more comprehensive analysis is required to verify compliance with the basic restrictions. The reference levels also limit the possibility of experiencing small shocks in strong external electric fields.

The recommended limit varies with the frequency of the ELF field. At a frequency of 50 Hertz (Hz) (the frequency of mains electricity), the reference levels for continuous exposures of the public are 200 microtesla ( $\mu\text{T}$ )<sup>5</sup> for the magnetic field and 5 kilovolts per metre (kV/m) for the electric field. For occupational exposures, the reference levels are 1,000  $\mu\text{T}$  and 10 kV/m respectively.<sup>6</sup>

Different limits are set for people exposed occupationally and for the general public. The main reason for this difference is that people exposed occupationally are adults, exposed under controlled conditions, who should receive training about potential risks and the precautions they should be taking. They should be aware, for example, of the possibilities of receiving small shocks when touching objects in a strong electric field. Occupational exposures are limited to the length of the working day and over the working lifetime.

The general public, on the other hand, includes individuals of all ages and in all states of health, who will not normally be aware of the exposure they are receiving. They can be exposed for 24 hours per day, and over a whole lifetime, and should not be expected to accept effects such as annoyance or pain due to small shocks and discharges.

The Ministry of Health recommends that the occupational limits should be applied only to people such as electricians or others who are aware of their exposures and trained in any precautions that might be necessary. In homes, offices and most other work sites, the public limits should apply.

In addition to compliance with the numerical limits in the ICNIRP guidelines, the Ministry encourages the use of low- or no-cost measures to reduce or avoid exposures, and supports this approach for siting new electrical facilities. This is consistent with a recommendation in the WHO (2007) review of ELF fields, and with Ministry recommendations with regard to exposures from other agents. It recognises that it is impossible to prove that any agent is absolutely safe, and that there are some areas where further research is being undertaken to complete our understanding of how ELF fields interact with the body. As discussed in Section 6.1, this approach has effectively been mandated in the 2008 National Policy Statement on Electricity Transmission made under the Resource Management Act 1991.

The Ministry's information booklet, *Electric and Magnetic Fields and Your Health* (Ministry of Health 2013) presents an overview of the nature and occurrence of ELF fields and the health effects research, along with the limits recommended by ICNIRP. The booklet is available in printed form and on the Ministry's website.

<sup>5</sup> The microtesla ( $\mu\text{T}$ ) is the unit for magnetic flux density measurement in the international system of units. Some literature on the subject uses an older unit, the milligauss (mG).  $1 \mu\text{T} = 10 \text{ mG}$ .

<sup>6</sup> The corresponding magnetic field reference levels in the 1998 ICNIRP guidelines were 100  $\mu\text{T}$  for the public and 500  $\mu\text{T}$  for occupational exposures. Electric field reference levels are unchanged. The main reason for the change in the magnetic field reference levels is improved dosimetry (ie, knowledge about the relationship between the external field to which someone is exposed and the electric field induced in the body by that field).

## 2.2 Radiofrequency fields

The Ministry of Health recommends using NZS 2772.1:1999 *Radiofrequency Fields Part 1: Maximum exposure levels – 3 kHz to 300 GHz* to manage exposure to RF fields. This standard is based on guidelines published in 1998 by ICNIRP, which are derived from a careful review of the health effects research and were reaffirmed in 2009 (ICNIRP 2009b) following a review of more recent research in this area (ICNIRP 2009a). ICNIRP is currently revising its 1998 guidelines, but has confirmed that it still considers them protective (ICNIRP 2017).

NZS 2772.1 sets limits for exposure to the RF fields produced by all types of transmitters and covers both public and occupational exposures. Occupational limits should normally be applied only to people who are expected to work on RF sources (eg, radio technicians and engineers, riggers, RF welder operators), who have received training about potential hazards and the precautions that they should take to avoid them. Their exposures to occupational levels would normally be limited to the working day and over their working lifetime. Occupational exposure limits are set at levels 10 times lower than the threshold at which the research data provides clear evidence that adverse health effects might occur. The public limits have a safety factor of 50.

As with ELF fields, NZS 2772.1 sets basic restrictions. At frequencies above 10 Gigahertz (GHz), these are based on the incident power flux density.<sup>7</sup> Below 10 GHz, the basic restriction sets a limit on the amount of RF power absorbed in the body (the **specific absorption rate**, SAR) and (at the low end of the frequency range covered by the standard) on the RF current density induced in the body.

SAR and induced current density are difficult to measure, so the standard also specifies reference levels in terms of quantities that are easier to measure (or calculate):

- electric and magnetic field strengths and plane wave equivalent power flux density
- currents flowing through a limb when in the presence of the field or when making point contact with a conductive object.

Compliance with the reference levels ensures compliance with the basic restrictions, and in many situations they can effectively be regarded as the NZS 2772.1 'exposure limits', although the standard does not use this term. If exposures exceed the reference levels, this does not necessarily mean the basic restriction has also been exceeded. However, as with ELF fields, a more comprehensive analysis is required before compliance can be verified.<sup>8</sup>

<sup>7</sup> Power flux density (sometimes just called 'power density') is the power per square metre carried by the radio wave across an area at right angles to the direction in which the radio wave travels.

<sup>8</sup> At frequencies between 100 kHz and 10 MHz, ICNIRP (and NZS 2772.1) requires assessment against limits based on both SAR and induced current density criteria. The limits based on induced current density criteria protect against nerve stimulation. The ICNIRP 2010 guidelines discussed in Section 2.1 provide limits to protect against nerve stimulation up to frequencies of 10 MHz, and overlap with limits serving the same purpose in NZS 2772.1. While the ICNIRP 2010 and NZS 2772.1 limits differ in some ways, for now the Committee considers that it would be acceptable to use either of them when assessing the likelihood of exposures causing nerve stimulation.

As well as compliance with the numerical limits, clause 10(d) of NZS 2772.1 requires:

Minimizing, as appropriate, RF exposure which is unnecessary or incidental to achievement of service objectives or process requirements, provided that this can be readily achieved at modest expense.

An explanatory note to this clause comments:

Notwithstanding that ICNIRP considers that the basic restrictions and reference levels in this Standard provide adequate protection, it is recognized that community concerns over RF exposure may be able to be addressed by further minimization of exposure in accordance with the requirements of Clause 10(d).

Effectively, this means that when installing RF transmitters, simple steps should be taken to minimise exposures if this can be achieved at low or no cost and without compromising the performance of the system. Options that can be considered when seeking to minimise exposures include:

- site selection – if several suitable sites are available that meet the desired coverage objectives, the one that results in the lowest exposures in public areas should be preferred, all other things being equal
- transmitter power – transmitter power should be set so as to provide coverage in the desired areas, but not beyond that
- antenna placement – particularly on rooftop sites, antennas should be placed so as to minimise exposures in adjacent areas, consistent with achieving the required coverage.

To function efficiently, many modern wireless technologies include features that automatically minimise exposures. Mobile phone base stations (cell sites), for example, adjust the transmitter power up and down so as to be just sufficient to handle traffic through the site, as this reduces interference. WiFi devices and access points do not transmit unless they are transferring data (apart from very brief polling signals).

Information about NZS 2772.1 is presented on the Ministry website, along with other information on specific sources of interest (eg, mobile phones and WiFi) and how people can reduce their exposures if they wish to do so.

A companion standard, AS/NZS 2772.2:2016 *Radiofrequency Fields Part 2: Principles and methods of measurement and computation – 3 kHz to 300 GHz*, sets out methods to assess compliance with the standard. This updates the 2011 version of that standard to provide additional guidance in estimating uncertainty and estimating exposures from dish and panel antennas, add some more worked examples and make some minor corrections and modifications to the text.

Concerns are sometimes expressed about the validity of NZS 2772.1 (see Appendix A).

ICNIRP recently published a consultation draft of revised RF exposure guidelines. While the draft contains some changes in detail, the fundamental basis and general shape of the limits are unchanged from the 1998 version.

# 3 Research on extremely low frequency fields

## 3.1 Introduction

For many years the key question relating to ELF fields and health has been whether long-term exposures to relatively high fields increases the risk of leukaemia in children. Although epidemiological studies find a small but consistent association, laboratory research does not provide any support for a link. Based on this finding, the International Agency for Research on Cancer (IARC) classified ELF magnetic fields as a 2B 'possible' carcinogen in 2002 (see Appendix B). Research activities in the past few years have slowed as it has been recognised that simply carrying out more studies similar to those that have been undertaken in the past is unlikely to make any progress.

## 3.2 Review by WHO in 2007

A milestone in the assessment of health effects caused by exposures to ELF fields was achieved in June 2007 with the publication of a substantial review in the WHO Environmental Health Criteria series. The WHO convened a task group to prepare the review, following its normal rules requiring a diversity of representation, agreement by consensus and freedom from actual or potential conflicts of interest.

The principal conclusions on health risks (Section 1.1.11 of the review) were as follows.

- There are established acute effects of exposure to strong ELF electromagnetic fields, and compliance with existing international guidelines provides adequate protection.
- Epidemiological studies suggest an increased risk of childhood leukaemia from long-term (ie, periods of years) average exposures greater than 0.3–0.4  $\mu\text{T}$ . Some aspects of the methodology of these studies introduce uncertainties in the hazard assessment. Laboratory evidence and mechanistic studies do not support a causal relationship, but the evidence is sufficiently strong to remain a concern.
- If the relationship is causal, ELF fields could be responsible for 0.2–4.9% of leukaemia cases worldwide. Hence the global impact on public health, if any, is limited and uncertain.
- Scientific data suggesting a link with other diseases (other childhood and adult cancers, depression, suicide, reproductive problems, developmental and immunological disorders, and neurological disease) is much weaker. However, in some cases (eg, cardiovascular disease, breast cancer), the evidence is sufficient to rule out a causal relationship.

On the basis of these findings, the task group recommended the following protective measures.

- Exposure limits such as those recommended by ICNIRP and the Institute of Electrical and Electronic Engineers (IEEE) (see Section 5.4) should be implemented to protect against the established acute effects of exposure to ELF electromagnetic fields (EMFs).
- In view of the conclusions on childhood leukaemia, the use of precautionary approaches is reasonable and warranted, but exposure limits should not be reduced arbitrarily in the name of precaution.
- Precautionary approaches should not compromise the health, social and economic benefits of electric power. Given the weakness of the link between exposures to ELF fields and childhood leukaemia, and the limited impact on public health if the relationship is causal, the benefits of reducing exposure are unclear, so the cost of precautionary measures should be very low.
- Very low-cost measures should be implemented when constructing new facilities and designing new equipment.
- When contemplating changes to existing ELF sources, ELF field reduction should be considered alongside safety, reliability and economic aspects.

At a workshop the WHO organised just after the release of the Environmental Health Criteria review, the chair of the task group spoke about the great deal of thought that had gone into the group's recommendations on exposure limits and what form of precautionary approach was justified. The task group had carefully considered the possibility of reducing exposure limits in response to the childhood leukaemia findings but felt that this could not be justified. Nor could it justify any other reduction to existing limits.

## 3.3 Work since publication of the WHO review

Since the WHO published its review, research has concentrated on two main areas:

- epidemiological work on childhood leukaemias and other cancers, including several meta-analyses
- neurodegenerative diseases (Alzheimer's disease, amyotrophic lateral sclerosis, etc).

A key part of this work has been to try to understand the origin of the association between the increased risk of childhood leukaemia related to chronic exposures to ELF magnetic fields greater than 0.3–0.4  $\mu\text{T}$  and, in particular, whether the fields or some other factor are responsible for the association.

## Epidemiological studies of childhood and other cancers

A few more epidemiological studies of childhood leukaemia incidence in relation to magnetic fields have been carried out since two major pooled analyses<sup>9</sup> of similar research were published in 2000. These formed the basis for a pooled analysis published in 2010, which concluded:

Our results are in line with previous pooled analyses showing an association between magnetic fields and childhood leukaemia. Overall, the association is weaker in the most recently conducted studies, but these studies are small and lack methodological improvements needed to resolve the apparent association. We conclude that recent studies on magnetic fields and childhood leukaemia do not alter the previous assessment that magnetic fields are possibly carcinogenic (Kheifets et al 2010b).

An editorial in the same journal asked whether, for childhood leukaemia studies of this type, 'enough is enough'. The authors commented:

As long as no emerging new ideas become apparent (eg, better exposure assessment, biological mechanism, important confounders), we should accept the limits of epidemiological research. This is mainly true, as the percentage of highly exposed children is below 1%, and the public health impact is low (Schmiedel and Blettner 2010).

A 2005 study on childhood leukaemia incidence in relation to transmission lines found increased risks of leukaemia associated with residence (at birth) at distances of up to 600 metres (m) from transmission lines (Draper et al 2005). These results did not appear compatible with an effect of magnetic fields, as the fields beyond distances of around 200 m would have been similar to, or less than, fields found from other sources in the home. An extension of this study looked at a longer period and additional lines (Bunch et al 2014). It found that the increased risk declined over time between 1962 and 2008, and the results did not support an effect of ELF magnetic fields. A further analysis reported that this decline in risk was linked to calendar year of birth or cancer occurrence (Bunch et al 2016). The same researchers, in a study on childhood leukaemia in relation to underground high voltage lines, found no association with either distance or calculated magnetic flux density (Bunch et al 2015). The low numbers of exposed subjects limited the study's power but the authors concluded that the absence of risk added to the argument that any risks from overhead lines may not be caused by magnetic fields.

A 1993 Danish study (Olsen et al 1993) on childhood leukaemia has also been updated, adding data up to 2003 (Pedersen et al 2015). Whereas the original study found elevated risks for childhood leukaemia, tumours of the central nervous system and malignant lymphoma, no elevated risks were found in the more recent data, and results for the whole period were consistent with the previous pooled analyses. There were few cases in the highest-exposure group.

<sup>9</sup> A pooled analysis combines the raw data from several studies.

A large study in California (Crespi et al 2016) also investigated childhood leukaemia incidence, and central nervous system cancers, in relation to distance from high-voltage lines. For childhood leukaemias it found a small but not significant increased risk within 50 m of a line, but no evidence of a risk beyond that, or of any risk for central nervous system cancers.

The epidemiological studies of childhood leukaemia, magnetic fields and proximity to high-voltage transmission lines have been subject to two recent re-analyses. Amoon et al (2018) published a pooled analysis of studies evaluating the risk of childhood leukaemia as a function of distance from high-voltage lines, and whether any risk could be due to magnetic fields or other factors associated with distance from lines. They found a small but not statistically significant increased risk associated with residence within 50 m of a line with a voltage higher than 200 kV that was not explained by high magnetic fields.

The Health Council of the Netherlands (2018), on the other hand, found that when it pooled the results of studies that it considered had the most comprehensive histories of magnetic field exposures of children, the risk of leukaemia was about 2.5 times greater in children that had been exposed to long-term average magnetic fields above 0.3–0.4  $\mu\text{T}$  – similar to the findings of the earlier meta-analyses. At present, only the executive summary of this report has been translated into English, so the details of this work have not been available to the Committee.

A pooled analysis of studies investigating childhood brain tumours in relation to ELF magnetic fields concluded that ‘These results provide little evidence for an association between ELF-MF exposure and childhood brain tumours’ (Kheifets et al 2010a). The recent Health Council of the Netherlands review also considered brain tumours in children. While it found a small increased risk, it considered that there was considerable uncertainty and that the findings could be attributed to chance.

The European Advanced Research on Interaction Mechanisms of electroMagnetic exposures with Organisms for Risk Assessment (ARIMMORA) research programme investigated possible mechanisms by which ELF fields might interact with cells and influence the development of childhood leukaemia. One of the key outcomes was the development of a transgenic mouse that has the same genes predisposing to leukaemia as are found in the most common form of childhood leukaemia. The programme also found cellular effects that could provide additional areas in which to investigate the interaction of ELF fields with cells. A risk assessment supported the WHO (2007) recommendations on taking simple precautions when planning new electrical infrastructure to reduce or avoid exposures (see Appendix C for a summary).

The WHO (2007) review considered that data on breast cancer was sufficient to rule out an association with ELF fields. Subsequently, a meta-analysis in 2013 concluded that there may be an association, but noted limitations in the data on which this finding was based (Chen et al 2013). Since then a further study found no association (Li et al 2013), and an accompanying editorial concluded that attention should now be focused on more promising avenues of research that could make a difference for public health and advance science (Feychting 2013).

## Neurodegenerative diseases

The WHO (2007) review noted that only a few studies had investigated possible links between Parkinson's disease, multiple sclerosis and ELF fields, and that there was no evidence for an association. Alzheimer's disease and amyotrophic lateral sclerosis (ALS) had been the subject of more studies, some of which suggested increased risks of ALS in people working in electrical industries. It was noted that electric shocks could be a confounder in such studies. Research on Alzheimer's disease gave inconsistent results, but the higher-quality studies focusing on morbidity rather than mortality tended not to find associations with ELF fields.

Further studies, both residential and occupational, have been published since then, along with some meta-analyses of occupational studies (Huss et al 2015; Vergara et al 2013; Zhou et al 2012). A difficulty in analysing these studies is that they used a range of methods to assess exposures, including job titles, measurements, self-reports and job-exposure matrices. Results still show considerable heterogeneity. For ALS, associations tend to be with job titles rather than with measured magnetic fields (Vergara et al 2015), but a more recent prospective study does support a relationship with magnetic field exposure (Koeman et al 2017). While research evidence indicates a weak association with Alzheimer's disease, there are concerns about both exposure assessment and disease misclassification. Most results for Parkinson's disease find no risk.

## Thresholds for perception of magnetophosphenes

A research group at the Lawson Health Research Institute, Canada has published several papers investigating the onset of magnetophosphene<sup>10</sup> perception, which forms the basis for the ICNIRP public limits. The only previous work in this area was carried out in the 1980s and had limited data. Comprehensive experiments by the Canadian group have established that at 50 Hz, magnetophosphenes are perceived at a magnetic flux density of around 15 milliteslas (well above the reference level for the public of 200 microtesla), and the sensitivity for detection is, as supposed, inversely proportional to frequency. The group's data suggests that the effect arises in the rod cells in the eye. The work has been extended to investigate possible effects on balance, as similar underlying interaction mechanisms may be involved.

<sup>10</sup> Phosphenes are sensations of light spots that are produced by something other than light, such as applying gentle pressure on the eyeball. Magnetophosphenes are produced by strong magnetic fields.

## 3.4 Overseas reviews in the past six years

No review has been devoted exclusively to ELF fields in the past six years, apart from a summary of the European ARIMMORA research programme (including its risk assessment) and the first part of a three-part review by the Health Council of the Netherlands (see Appendix C for a summary). ELF fields have been included in more general reviews of the whole EMF area by a few groups (see also Appendix C). These groups note that open questions remain over the childhood leukaemia data and that, while some research on Alzheimer's disease and ALS reports associations, no clear pattern emerges.

## 3.5 Future work

A few novel approaches to resolving the childhood leukaemia question have been suggested. The intention is to identify a cohort with a relatively high proportion of exposed individuals, or a higher than normal background incidence of childhood leukaemia, to avoid the weaknesses identified in case-control studies carried out to date. Suggestions include studying children living in apartment buildings, in which exposures in ground or first-floor apartments adjacent to a built-in mains transformer are found to be markedly higher than in other apartments; and studying children with Down syndrome, who have a much greater risk of leukaemia than other children. Some preliminary work in these areas has been published.

In addition, a new type of transgenic mouse has been developed, which better models the development of childhood leukaemia and was used in an ARIMMORA project.

In association with an expansion of the electricity grid (necessitated by the move away from nuclear power to renewable energy sources), a large research programme has been launched in Germany. Areas covered include neurodegenerative diseases, childhood leukaemia, miscarriage, corona discharge and risk communication.

## 3.6 Conclusions

Overall, the picture is still largely unchanged since the publication of the WHO (2007) review. The possibility that long-term exposures to relatively strong magnetic fields (albeit low in comparison with the recommended exposure limits) somehow increases the risk of developing childhood leukaemia remains an open question. The results from epidemiological studies are not supported by laboratory research, and researchers agree that even if a causal relationship existed, ELF magnetic fields would be responsible for only a small fraction of childhood leukaemia cases. Research on possible links with neurodegenerative diseases has not provided consistent results.

# 4 Research on radiofrequency fields

## 4.1 Introduction

Applications and uses of technology incorporating radio transmitters have burgeoned over the past few years and are likely to continue to do so. Many new devices communicate over mobile phone networks or WiFi, and networks using these technologies have expanded considerably. Some of the new technologies and applications are discussed in Section 6.2.

Many research studies on the possible health effects of exposures to RF fields, especially at levels that comply with current exposure limits, and at frequencies used by modern communication technologies, have been published in recent years. This section discusses some of the key areas of interest. Several health and scientific bodies have periodically reviewed recent research; typically two to four such reviews are published every year (see Section 4.6 and Appendix D for summaries).

## 4.2 RF and cancer

### Interphone and other studies on mobile phones and brain tumours

One of the key research topics is whether mobile phone use (in particular, when the phone is held up to the ear) is associated with an increased risk of brain tumours. There are two main groups of investigations (the Interphone study and the Hardell group studies), as well as some other case-control and cohort studies, and cancer registry studies. Several meta-analyses have also been conducted.

#### The Interphone study

The Interphone study was coordinated by IARC and initiated in 1999. Fourteen research centres around the world (including one in New Zealand) followed an identical research protocol in case-control studies investigating the incidence of three types of brain tumour (meningioma, glioma and acoustic neuroma) in mobile phone users. Additional work attempted to assess the reliability of the data collected.

The findings on meningioma and glioma were reported in 2010 (Interphone Study Group 2010), and on acoustic neuroma in 2011 (Interphone Study Group 2011). For meningioma and glioma, the Interphone group concluded:

Overall, no increase in risk of glioma or meningioma was observed with use of mobile phones. There were suggestions of an increased risk of glioma at the highest exposure levels, but biases and error prevent a causal interpretation. The possible effects of long-term heavy use of mobile phones require further investigation.

The 'suggestions of increased risk' for glioma were observed in people who reported a cumulative call time greater than 1,640 hours, but no increased risk was found for shorter call times. However, the researchers noted biases in the data (such as a tendency for people with brain tumours to overestimate their past use), which could account for the apparent increased risk.

Findings for acoustic neuroma were similar to those for glioma.

The Interphone data has also been used in two further studies, using different methods, that looked at glioma location in relation to the part of the brain that received the highest RF exposure. One of these (using data from five, mainly non-European, Interphone study centres) found an increased risk of tumours in the part of the brain with the highest exposure, while the other (using data from seven European study centres) did not.

## Hardell group

A Swedish group under Lennart Hardell has published a series of case-control studies examining brain tumours in parts of Sweden in relation to both mobile phone and cordless phone use. The same group has also published several pooled analyses of its data. Overall, these studies find associations between gliomas and acoustic neuroma and all types of wireless phone use, which increases with the number of years a person has been using a phone and with cumulative hours of use.

No explanation has been found for the differences between results from the Hardell and Interphone studies (which included a research centre in Sweden), although the greater quality control and accompanying data validation studies carried out by Interphone have been noted.

## Cohort studies

There has been follow-up of a Danish cohort of some 420,000 people who signed a mobile phone subscription between 1982 and 1995. Findings have been published in 2002 and 2011 and show no increased risk of brain tumours. This continuing study has several strengths and weaknesses (see, for example, the discussion in Frei et al 2011), but it is generally considered that the weaknesses do not prevent it from providing useful information.

A second cohort study has been carried out in the United Kingdom, which followed up 791,710 women over seven years. Mobile phone use was not associated with brain tumours or non-central nervous system cancers (Benson et al 2013a, 2013b).

## Registry studies

Several studies of trends in incidence or mortality rates in cancer registry data have examined whether any changes to trends in brain tumour incidence might correlate with the increased use of mobile phones (eg, Chapman et al 2016, Australia; de Vocht et al 2011, UK; Deltour et al 2012, Scandinavia; Kim et al 2015, New Zealand; Little et al 2012, United States of America). No such changes are evident, and while the data seems to exclude risks of the magnitude suggested by the Hardell studies, it is not yet sufficient to exclude either a small risk of the magnitude suggested by the Interphone study or latencies<sup>11</sup> greater than around 10–15 years.

De Vocht (2016) took a different approach, comparing actual brain tumour incidence trends in the UK with modelled trends based on data up to some cut-off time at which it was hypothesised that mobile phone use might start to exert an effect. He found that if the latency was assumed to be 10 years, malignant neoplasms of the temporal lobe (which generally experiences the highest exposure from mobile phones) exceeded the expected rate.

## IARC classification

IARC assembled a working group in 2011 to review the research on RF fields and cancer and to determine where they fit into its classification scheme. The group concluded that exposures to RF fields fell into Group 2B – a ‘possible’ human carcinogen. This finding was based mainly on associations (ie, correlations) between heavy use of mobile phones and an increased risk of glioma, but the 2B classification means that while a causal relationship may be possible, chance, bias or confounding cannot be ruled out as an explanation for the association.

The working group also noted that while none of the studies in which animals were exposed over long periods showed an increased incidence of any tumour type, some experiments in which RF exposures were combined with a known carcinogen did. Other data provided only weak evidence of mechanisms relevant to an effect on cancer (Baan et al 2011).

The IARC classification has received widespread publicity. A paper by the working group chair and IARC staff published subsequently noted:

The classification as possibly carcinogenic to humans was trivialized by some who compared it with other agents having a 2B classification and acclaimed by others who found justification for their opinion that mobile phones present a danger. The subtlety of the 2B classification – that there is some, albeit uncertain evidence of risk, precluding classification as conveying no risk (Group 4) – proved difficult to communicate and did not fit well with media seeking a more definitive position.

<sup>11</sup> Periods between when a cancer-causing or promoting exposure first occurred and the appearance of the cancer.

Communication was further complicated by the restriction of the IARC Monograph Program to hazard identification because IARC does not quantify risk. A classification as possibly carcinogenic to humans may be misinterpreted by a lay person, meaning that there is indeed an increase in risk, but it is small. Although an underlying 'weak association' may reduce the certainty with which a hazard identification is made, the 'possible' categorization does not refer at all to the size of risk, but only to the strength of evidence (Samet et al 2014).

The difficulties of communicating the meaning of the IARC finding were also discussed by Wiedemann et al (2014). They found that educated non-experts were likely to misunderstand both the characterisation of the probability of carcinogenicity and the quantitative risk increase presented in the IARC press release.

The main difficulty appears to be that IARC apply a very strict technical definition to an everyday term ('possible'), which is normally applied very loosely, so it is not too surprising that different people draw quite different conclusions as to what is really meant. Perhaps the key consideration is that IARC only refers to the quality of the evidence suggesting that there is a risk, and it considers this evidence to be 'uncertain'.

Section 4.6 discusses conclusions on brain tumour risks that health groups have drawn after reviewing the data since the IARC classification. However, it is worth mentioning that almost all of the epidemiological data that went into the IARC review was based on GSM (2G) or older-generation mobile phones, which typically operate at powers 50–100 times greater than 3G phones, and so produce exposures to the head that are correspondingly higher. For example, widespread roll-out of 3G networks in New Zealand only started in 2005 (although Telecom, as it was known then, introduced a predecessor (CDMA2000), with handsets that also tended to operate at lower power than GSM, in 2001). All three mobile networks now provide a 3G service over the whole country.

## United States National Toxicology Programme study

A large US National Toxicology Programme (NTP) study investigated carcinogenicity in rats and mice exposed to GSM- and CDMA-modulated mobile phone signals for several hours per day, over periods of up to two years. Draft reports of the completed study were published in February 2018 (NTP 2018a, 2018b) and the findings of a peer review panel in April 2018 (NTP 2018c). Final reports are not yet available, however.

The draft reports concluded that there was 'some evidence'<sup>12</sup> of carcinogenic activity of RF fields in the rats. This was based on an increased incidence of malignant schwannomas in the heart in male rats, but not the females. The incidence of malignant schwannomas did not increase in either male or female mice. Findings were also equivocal for cancers in a few other organs, but in general these were not evident for both of the two different modulations used, or in both males and females. Similarly a

<sup>12</sup> The NTP uses a four-category scale in its evaluation, based on the strength of the evidence: clear evidence, some evidence, equivocal evidence and no evidence. A fifth category, inadequate study, is used when the data has limitations that prevent any interpretation.

few findings were equivocal in mice but generally showed no consistent pattern in terms of modulation or the sex of the mouse.

The NTP noted that the RF levels used, and exposure durations, were greater than people would experience from mobile phone use, and exposed the whole body rather than localised areas of the animal. It cautioned against extrapolating the results to mobile phone use. One of the difficulties in interpreting the results was that the control (unexposed) rats had a much lower survival rate than those that had been exposed.

The peer review panel agreed with the NTP conclusions on the mice study. For the rats, however, it recommended changing the conclusions on malignant schwannoma in the heart to 'clear evidence', and changing a few of the 'equivocal evidence' conclusions to 'some evidence'. The NTP is now considering the peer review panel's report before finalising its own reports and conclusions.

In the meantime, NTP and Japanese researchers have proposed further studies to explore the findings of the NTP study further. The NTP is considering work on mechanisms and also using different modulations. The Japanese researchers propose investigating whether the exposures could have increased body temperature (which they were not supposed to) and whether some of the findings, such as the poor survival of controls, could have been due to uneven assignment of mothers to the exposed and control groups.

In a note on the NTP findings, ICNIRP (2018) raises concerns about the possibility of the exposures heating the heart (which may not have been detected by the subcutaneous temperature measurements made by NTP). It is also concerned that no statistical correction was made for multiple comparisons (given that the more outcomes that a study investigates, the more likely it is that some will appear to be statistically significant through chance alone).

Publication of the final reports is expected in late 2018.

## 4.3 Electrohypersensitivity and other symptoms

Electrohypersensitivity (EHS) is the name given to a range of symptoms such as headaches, tiredness, dizziness, sleep disturbances and aching muscles, which some people attribute to EMF exposures. Although both ELF and RF fields have been suggested as a cause of the symptoms, most of the concern and research have focused on RF fields. The WHO, following a workshop on the topic in 2004, concluded that double-blind studies that are well controlled and well conducted showed that the symptoms do not seem to be correlated with EMF exposure (Mild et al 2006). For this reason, it proposed using the term 'idiopathic environmental intolerance with attribution to EMF' (IEI-EMF) instead of EHS, to remove any causal implications.

Since the WHO workshop, further laboratory and observational studies have been carried out. Recent reviews of these studies continue to conclude that people who consider themselves unusually sensitive to EMFs are, in fact, unable to detect EMFs, and the occurrence of symptoms appears unrelated to exposures (see, for example, Baliatsas et al 2012; Rubin et al 2011). Experimental evidence suggests a placebo effect (ie, the symptoms develop when someone believes that they are exposed, even when they are not).

A criticism of these studies is that they take place in an unfamiliar laboratory setting and involve short-term exposures, rather than long-term exposures in a 'normal' environment. Yet many people who consider that they suffer from EHS report experiencing symptoms very soon after exposure starts. A few studies that address those concerns, including studies on quality of sleep (Danker-Hopfe et al 2010; Mohler et al 2012) and on a variety of health complaints including sleep disturbance, headaches, and poor physical health (Berg-Beckhoff et al 2009), do not support a role for EMF in the development of EHS symptoms. In addition, a recent study involving tests in the home found that no participants could correctly identify when they were being exposed (van Moorselaar et al 2016). Similar findings came from a home-based study in Australia (Verrender et al 2017).

A comprehensive French review (ANSES 2018) found that while the pain and suffering reported by sufferers is real, no clear diagnostic criteria exist and studies have shown that the development of symptoms is unrelated to exposure. Few other possible causes have been investigated.

Although more properly classed with ELF fields, so-called 'Dirty Electricity' (DE) is an agent that some have held responsible for a wide range of symptoms and diseases. DE is defined as high-frequency voltage transients (between about 4 kilohertz (kHz) and 100 kHz) superimposed on a 50/60 Hz mains electricity supply. It may arise, for example, through the use of compact fluorescent lamps or switch mode power supplies. A systematic review published in 2016 found that the evidence base for any effects is poor and does not stand up to scientific scrutiny (de Vocht et al 2016).

## 4.4 Children

The possibility that children might be more sensitive to the effects of RF fields was highlighted by the UK Independent Expert Group on Mobile Phones (2000) report (sometimes referred to as the Stewart Report). The reasoning was that children have a longer lifetime of exposure than adults, their nervous system is still developing and, because they have higher tissue conductivity and thinner skulls, their brains would absorb more RF energy than adults. A 2004 WHO workshop on children and EMF (Repacholi et al 2005) noted that no direct evidence of greater vulnerability in children was available, but neither had much research directly addressed the question, and a research agenda was drafted to fill the main gaps in knowledge.

Since then, research that is directly relevant to children has been reported in the areas of:

- dosimetry (ie, the relationship between external fields to which someone is exposed and the RF power absorbed in the body)
- cancer risks related to mobile phone use and residence near broadcast transmitters
- cognitive effects
- developmental studies in animals and humans.

In addition, three research reviews covering aspects of children's health have been published (ANSES 2016; Health Council of the Netherlands 2011; Wiedemann et al 2009), as well as being addressed in a WHO workshop in 2011 (McKinlay et al 2011).

The dosimetry studies have confirmed that some parts of a child's head absorb RF fields from a mobile phone more than for adults, but the effect may be frequency dependent and less pronounced at ages greater than eight years. However, the maximum absorption (the highest SAR value) is similar for adults and children, and existing protocols for testing phones are conservative for both (Foster and Chou 2014).

Dosimetry studies looking at whole-body exposures have found that under some conditions, exposures at frequencies around 100 megahertz (MHz) and 1 GHz that comply with the reference levels may result in the basic restriction being exceeded in children. The amount by which the basic restriction is exceeded, however, is small in comparison with the safety factor of 50, and no adverse effects are anticipated.

One study investigating brain tumour risks in relation to mobile phone use by children concluded that there is no association (Aydin et al 2011). This conclusion was supported by cancer registry data. Overall, studies investigating childhood cancer incidence near broadcast transmitters suggest there is no increased risk associated with increased exposure, but these studies would most likely not pick up a small increased risk, and exposures are quite low.

Other research on development, cognition and related areas has, overall, not found that children are especially susceptible to any effects of RF fields. The Health Council of the Netherlands (2011) review on the influence of RF fields on children's brain function concluded that there was no cause for concern, but that effects could not be ruled out and further research on possible long-term effects was needed. The Julich review found that the existing scientific evidence did not suggest that children's health is affected by RF from mobile phones or cell sites, but that evidence in some areas was limited and further research was needed (Wiedemann et al 2009). The ANSES (2016) review found that evidence is insufficient to draw firm conclusions in many areas, but did not consider that existing exposure limits needed to be changed.

A series of papers reporting prospective studies on a group of Swiss adolescents has investigated exposures from, and use of, wireless devices and outcomes such as memory performance, symptoms and behaviour. The studies found no clear correlations apart from a possible effect on memory performance (Schoeni et al 2015). Similarly no association was evident between exposures to fixed transmitters and symptoms and wellbeing in the same group. A prospective cohort study in Australia found limited evidence that changes in wireless phone use were associated with changes in cognitive function (Bhatt et al 2017).

## 4.5 EEG effects

A number of studies have investigated the effects of exposures to mobile-phone-like signals on the brain's electrical activity recorded in the electroencephalogram (EEG). Some researchers report finding changes in some frequency bands of the EEG during some phases of sleep following exposure to mobile-phone-type signals before sleep. The changes are small (eg, they have been described as smaller than those that occur after blinking) and do not seem to involve any effects on sleep quality, or implications for health. There also appear to be considerable differences between individuals. Recent work at the University of Wollongong suggests that some underlying thermal mechanism may be at work. The same group has also suggested that cognitive effects may occur – a finding contrary to previous results, which the group considers may not have been based on sufficiently sensitive experimental tests (Verrender et al 2016).

## 4.6 Recent overseas reviews

Several reviews of research into the effects of RF fields on health have been prepared by national and international health bodies in recent years. Appendix D summarises reviews published since January 2012. Overall, these reviews conclude that while weak evidence suggests that heavy use of mobile phones may be associated with an increased risk of brain tumours, further research is needed to clarify this. Most reviews consider that for periods of use up to 12–15 years, mobile phone use has no effect on brain tumour incidence, and some suggest that research reported since the IARC evaluation negates any link with cancer risk. For links to these reviews, see the Ministry's website.

The BioInitiative Report, first published in 2007 and partially updated in 2012, 2014 and 2017, is sometimes cited by people concerned about the possible health effects of exposures to RF fields. The Committee finds that this report has weaknesses that undermine its credibility and conclusions, and does not place any weight on the report's findings or recommendations. For more detail, see Appendix E.

## 4.7 Future work

Several large projects investigating aspects of RF exposures and health are in progress.

The MOBI-Kids study (which is similar to the Interphone study but looking at mobile phone use and brain tumours in children) is being carried out in 14 countries (including New Zealand, where the research group has received funding of \$466,148 from the Health Research Council). Data analysis is currently in progress.

A research programme funded by a levy on the telecommunications industry has been established in Australia at the Australian Centre for Electromagnetic Bioeffects Research, a National Health and Medical Research Council centre of research excellence.<sup>13</sup> The research programme covers a diverse range of interests, including epidemiology (for which Professor Mark Elwood of the University of Auckland is the chief investigator), animal and cellular studies, dosimetry, human neurophysiology and risk communication (Loughran et al 2016). The Australian Radiation Protection and Nuclear Safety Agency has published recommendations for future research recently (ARPANSA 2017).

The Cohort Study of Mobile Phone Use and Health (COSMOS), which started in six European countries in 2007, is tracking the health of 350,000 adult mobile phone users for 20 to 30 years, with a focus on outcomes such as brain tumours and cerebrovascular diseases, and symptoms such as headaches and sleep disorders. A strength of this study is that exposure information will be obtained from ongoing questionnaires and operator traffic records rather than having to rely on the study participants' memories. The first results, presented in mid 2018, showed no relationship between mobile phone use and tinnitus, headaches and hearing loss in participants from Sweden and Finland.

Several European research programmes are in progress, including GERoNiMO (Generalized EMF Research using Novel Methods. An integrated approach: from research to risk assessment and support to risk management),<sup>14</sup> and the UK-based SCAMP (Study of Cognition, Adolescents and Mobile Phones) programme.<sup>15</sup>

The WHO EMF Project monograph on RF fields, to be published in the WHO Environmental Health Criteria series, is still being prepared. The WHO has recently adopted stricter criteria for the preparation of such documents, and co-publication with NGOs such as ICNIRP. To hasten publication and make use of the extensive material already prepared, the WHO has decided to publish initially a 'Technical Document' that will include the narrative reviews already prepared, updated to June 2018. It will provide conclusions for the clear-cut health outcomes, and will recommend systematic reviews for health outcomes for which the evidence does not provide consensus. It will not, however, include any recommendations for WHO member states.

ICNIRP has published a consultation draft of its RF exposure guidelines. The main changes are to provide a more detailed scientific grounding of the limits, and to refine temporal and spatial averaging, and the treatment of pulsed sources, at frequencies above 6 GHz. In many respects, the proposed limits are similar to those in ICNIRP's current RF guidelines (ICNIRP 1998), and many types of transmitter (FM radio, television, mobile phone services, WiFi) will be unaffected. Consultation closed in October 2018.

<sup>13</sup> <http://acebr.uow.edu.au>

<sup>14</sup> <http://radiation.isglobal.org/index.php/en/geronimo-home>

<sup>15</sup> [www.scampstudy.org](http://www.scampstudy.org)

## 4.8 Conclusions

While a great deal of research has investigated the potential effects of exposures to RF fields on health, particularly exposures associated with mobile phone use, it has provided no clear indications of health effects caused by exposures that comply with the limits in the New Zealand RF field exposure standard.

Although the research results on mobile phone use and brain tumours led IARC to classify RF fields as a 'possible' carcinogen, it considered that these results could have arisen from chance, bias or confounding, rather than reflecting a true cause-and-effect relationship. Several reviews and meta-analyses published since the IARC assessment (eg, Lagorio and Roosli 2013; Repacholi et al 2012) consider that more recent research weighs against the existence of a cause-and-effect relationship, while others (eg, Yang et al 2017) note increased risks of health outcomes such as gliomas associated with long-term mobile phone use but also comment on the biases in the data and its poor quality and limited quantity. The complexity of the existing data and difficulties in making further progress have also been highlighted (Elwood 2014).

Animal studies have generally been interpreted as not supporting any effect of RF fields on cancer, but one recent animal study appeared to replicate a previous publication suggesting that RF fields could promote cancer (Lerchl et al 2015). Others, however, have treated the results cautiously, citing what they consider to be weaknesses in the study design and interpretation of the results (Nesslany et al 2015). A large animal study in the USA (NRP 2018b) found 'some evidence' of a carcinogenic effect at very high exposures, but the final report, taking account of peer review comments (that suggested the finding should be changed to 'clear evidence'), has yet to be published.

Recent dosimetry work has found that at some frequencies the reference levels in the New Zealand Standard are not as conservative as expected, and that under some circumstances the basic restriction may be exceeded when small children are exposed to fields that are close to the reference level. This is not of immediate concern for two reasons: first, measurements in New Zealand show that exposures in areas where children might be expected are always much lower than the reference level (so the basic restriction will never be exceeded) and, second, the amount by which the basic restriction might be exceeded is small in comparison with the safety factor of 50 built into the basic restriction. Nevertheless, this should be addressed in the medium term once the WHO RF review has been published and in ICNIRP's review of its RF exposure guidelines.

# 5 Exposure limits in other jurisdictions

## 5.1 Australia

### ELF fields

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) recommends the use of the ICNIRP 2010 guidelines as being in line with international best practice.

### RF fields

ARPANSA published RF exposure limits in 2002 in Radiation Protection Series 3 (RPS3). The numerical limits themselves, and the general requirements of the standard, are very similar to NZS 2772.1:1999. However, RPS3 includes more detailed supporting information providing the rationale for the standard and other supplementary material. In 2014 ARPANSA published a review of more recent research literature (discussed in Appendix D) to help determine whether the standard should be revised.

## 5.2 European Union

### Public exposures

The European Union (EU) can make recommendations on public exposure limits in member states but is unable to impose them. In 1999 the Council of the EU recommended that member states adopt the 1998 ICNIRP guidelines (Council of the EU 1999). A 2017 survey found that 21 EU countries either had adopted the ELF 50 Hz limits (by regulation or recommendation) or had no limits (Stam 2017). Some of these countries may also have recommendations or policies to minimise exposures if this can be done at reasonable cost and with reasonable consequences. The remaining seven had adopted a range of measures, including lower limits, lower limits applied to new electrical infrastructure near 'sensitive areas' (eg, homes, playgrounds, schools), specified separation distances between homes and new electrical infrastructure, and the adoption of measures at 'reasonable' cost if average exposures exceed specified thresholds.

For RF limits (eg, at the frequencies around 900 MHz used by cell sites), 19 EU countries had either adopted the recommended limits (by regulation or recommendation) or had more relaxed or no limits. The others had taken a variety of approaches, including:

- lower limits that apply everywhere (ranging from 70% to 1% of the EU recommended power flux density limit)
- a lower limit applied to each antenna
- lower limits that apply in 'sensitive areas'.

Some countries have regional variations.

Where lower limits have been adopted, the levels chosen appear to be set on the basis of what levels exist already and what can be achieved with existing technology, rather than being derived from an analysis of the health research. However, 'precaution' is often cited as a reason for setting lower limits. In one instance, the limits have been raised subsequently to accommodate new technology. Exposure surveys in Europe have found no systematic differences in exposure levels between countries that follow the EU recommendation and those that have lower limits (Thuroczy and Gajsek 2011; Urbinello et al 2014).

The UK recommends using the ICNIRP 1998 guidelines for public exposure.

## Occupational exposures

The EU Directive 2013/35/EU on occupational exposures to EMFs (which is based on the ICNIRP 2010 low-frequency guidelines, and the ICNIRP 1998 guidelines at higher frequencies) has now been transposed into national legislation by member states.

A non-binding guide to assist member states and businesses with the implementation of the Directive was published in 2016 (Directorate-General for Employment, Social Affairs and Inclusion 2016). The three volumes include a short guide for small businesses to help them decide what action, if any, they need to take, a detailed guide on practical implementation of the Directive if actions are required, and 12 case studies covering areas such as offices, welding and rooftop antennas. The information in this non-binding guide would be relevant to occupational health and safety assessments in New Zealand.

## 5.3 Canada

Health Canada (2015) has developed exposure guidelines for RF fields, *Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz – Safety Code 6 (2015)* (known as SC6). An accompanying document, the *Technical Guide for Interpretation and Compliance Assessment of Health Canada's Radiofrequency Exposure Guidelines*, contains technical information to assist in understanding the requirements of SC6. It also provides recommended best practice for ensuring compliance with the maximum exposure levels, and information on RF survey methods and examples of calculations.

The SC6 basic restrictions are broadly similar to those in the ICNIRP (1998) guidelines (and the 2010 guidelines for limits related to nerve stimulation at frequencies up to 10 MHz). However, the localised SAR restrictions in the head, neck and trunk for public and occupational exposures<sup>16</sup> are set at 1.6 and 8 Watts per kilogram (W/kg) respectively, averaged over 1 gram of tissue, rather than ICNIRP's 2 and 10 W/kg averaged over 10 grams of tissue.

Health Canada commissioned the Royal Society of Canada to review and comment on the Code before it was published (see Appendix D for a summary of the findings). The reference levels take into account recent dosimetry findings (see Section 4.4), and so are set somewhat lower than the ICNIRP's over much of the frequency range in order to be certain of maintaining the required safety factors under all circumstances.

At present there are no Canadian government guidelines for exposure to ELF fields. Health Canada considers guidelines are not necessary because the scientific evidence is not strong enough to conclude that typical exposures cause health problems.

## 5.4 Institute of Electrical and Electronic Engineers and International Committee on Electromagnetic Safety

The Institute of Electrical and Electronic Engineers (IEEE) has developed standards for electromagnetic fields since the 1960s. This work is now undertaken by the International Committee on Electromagnetic Safety (ICES), which operates under the rules and oversight of the IEEE Standards Association Standards Board to develop standards for the safe use of electromagnetic energy at ELF and RF frequencies. This includes both exposure and exposure assessment standards. Membership of ICES is open to anyone. A review of the IEEE/ICES ELF and RF limits is in progress and should be published by the end of 2018.

### ELF fields

The IEEE/ICES C95.6 standard (published in 2002 and reaffirmed in 2007) covers ELF fields up to 3 kHz (IEEE Standards Coordinating Committee 2007). While the fundamental concepts behind the IEEE/ICES limits are very similar to the ICNIRP 2010 ELF guidelines, they differ in some significant ways. The IEEE/ICES limits (especially the reference levels, which IEEE/ICES call 'maximum permissible exposures') are generally more relaxed than ICNIRP's. (For example, at 50 Hz, ICNIRP recommends a reference level for the public of 200  $\mu$ T, compared with the IEEE/ICES recommendation of

<sup>16</sup> SC6 uses 'uncontrolled' and 'controlled' environments, rather than 'public' and 'occupational' exposures, but the terms are largely equivalent.

904  $\mu\text{T}$ .) These differences arise for a number of reasons, such as the choice of safety factors and the models used to derive reference levels from basic restrictions.

## RF fields

The IEEE/ICES C95.1 standard (IEEE International Committee on Electromagnetic Safety 2005) and ICNIRP also share very similar fundamental concepts in relation to radiofrequencies. At frequencies above about 10 MHz, the reference levels for the public are similar, but larger differences occur at lower frequencies, with the IEEE/ICES limits generally more relaxed. IEEE/ICES occupational reference levels are also more relaxed than ICNIRP occupational reference levels at higher frequencies (above 300 MHz).

# 5.5 United States of America

## Public exposures

The US Federal Communications Commission (FCC) sets the rules on allowable levels of public exposure to RF fields in the USA and published its regulations in 1996.<sup>17</sup> The limits are a combination of limits recommended in National Council on Radiation Protection Report 86 and the 1991 version of the IEEE/ICES C95.1 standard. A review of these limits is currently in progress.

No national regulations cover ELF fields, but some states have adopted their own limits for magnetic fields at the edge of power line rights-of-way. These vary from 15 to 25  $\mu\text{T}$ .

## Occupational exposures

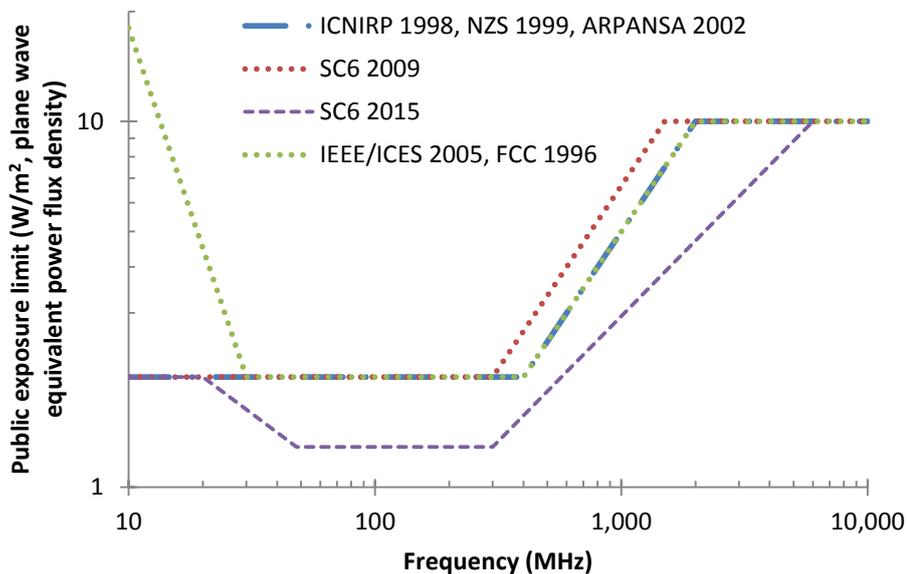
The US Federal Government does not set any limits on occupational exposures at ELF or RF frequencies. The American Conference of Government Industrial Hygienists, an organisation made up of industrial hygienists from within and outside government, recommends limits for a number of physical agents, including non-ionising fields. For 60 Hz ELF fields it recommends limits of 1,000  $\mu\text{T}$  and 25 kV/m for magnetic and electric fields respectively, and for RF fields it follows the IEEE/ICES occupational recommendations.

<sup>17</sup> A list of references is available at [www.fcc.gov/encyclopedia/radio-frequency-safety](http://www.fcc.gov/encyclopedia/radio-frequency-safety)

## 5.6 Comparison of limits for RF field exposures

Figure 1 plots the public reference levels (plane wave equivalent power flux density) recommended by ICNIRP, ARPANSA, Health Canada (SC6), IEEE/ICES and the FCC for frequencies between 10 MHz and 10 GHz.

**Figure 1: RF field reference levels recommended by various organisations**



Note: ARPANSA = Australian Radiation Protection and Nuclear Safety Agency; FCC = Federal Communications Commission; ICNIRP = IEEE/ICES = Institute of Electrical and Electronic Engineers International Committee on Electromagnetic Safety; NZS = New Zealand Standard; SC6 = Health Canada exposure guidelines.

## 5.7 Other countries

The WHO has a database of exposure limits on its Global Health observatory at <http://apps.who.int/gho/data/node.main.EMFLIMITS?lang=en>

# 6 Issues in New Zealand

## 6.1 How current legislation covers exposures in New Zealand

### Environmental exposures

#### ELF fields

Two instruments under the Resource Management Act 1991 provide national guidance for controls on exposures to ELF fields from transmission lines and associated infrastructure. First, Policy 9 of the 2008 National Policy Statement on Electricity Transmission (the Transmission NPS) states that:

Provisions dealing with electric and magnetic fields associated with the electricity transmission network must be based on the International Commission on Non-Ionising Radiation Protection *Guidelines for Limiting Exposure to Time Varying Electric Magnetic Fields (up to 300 GHz)* (Health Physics, 1998, 74(4): 494–522) and recommendations from the World Health Organisation monograph *Environment Health Criteria* (No 238, June 2007) or revisions thereof and any applicable New Zealand standards or national environmental standards.

The policy 'is to be applied by decision-makers under the Act'. So it has the effect of requiring any rules or decisions about ELF fields from the national grid to be based on the ICNIRP 2010 guidelines (the successor to the 1998 guidelines) and the WHO recommendations (see Section 3.2 for a summary).

The second guidance instrument, the Resource Management (National Environmental Standards for Electricity Transmission Activities) Regulations 2009, requires that following certain types of upgrade or maintenance work to pre-2010 transmission lines, the electric and magnetic fields should comply with the (now superseded) ICNIRP (1998) guidelines. An evaluation of these regulations is in progress, and this may provide an opportunity to consider referencing the ICNIRP 2010 guidelines, which the Ministry of Health recommends using.

Both instruments only apply to transmission lines (and, in the case of the Transmission NPS, associated infrastructure such as substations), rather than to other areas such as local electricity distribution infrastructure. Some district plans have guidance based on the Transmission NPS and also cover other activities that produce ELF fields.

## RF fields

The Resource Management (National Environmental Standards for Telecommunication Facilities) Regulations 2016 (the NESTF) updated the 2008 Regulations but the requirements concerning exposures to RF fields are essentially unchanged.

Clause 55 requires that when network operators establish a telecommunication facility:

- the site should be designed and operated in accordance with NZS 2772.1:1999
- before a site is established, the operator must assess exposures in publicly accessible areas in the vicinity (both from the proposed site and other transmitters nearby) and submit a report to the local authority confirming that exposures comply with the limits
- if the exposures in publicly accessible areas are calculated to exceed 25% of the limits, then a further report providing evidence that exposures comply with the limits should be prepared within three months of the site becoming operational.

The main change since 2008 is that the NESTF now references AS/NZS 2772.2:2016 in matters concerning the assessment of exposures (by calculation or measurement), rather than the old NZS 6609.2:1990. The NESTF User Guide has also been updated.

This requirement only applies to network operators as defined under the Telecommunications Act 2001. This includes mobile phone network operators, and broadcasters such as Kordia, but does not cover, for example, amateur radio operators.

Local authorities are unable to override these requirements, but they may also include non-network operators through provisions in their district plans.

## Occupational exposures

No explicit limits are set on EMF exposures from personal devices (eg, hand-held radios) or equipment used in the workplace (eg, high-frequency plastic welders). In practice, occupational exposures, either from equipment or from personal devices, would come under the scope of the employer's obligations to maintain safe working environments and practices. Equipment that may produce potentially hazardous levels of EMF should be identified and the exposures managed.

In some situations and industries, this process is reasonably straightforward. Operators of major broadcast facilities, for example, are well aware of the potential hazards, areas where these may be present, and the steps to take to avoid, remedy or mitigate them. Awareness may be lower in other circumstances, however, such as where small employers are using high-frequency welding equipment.

## Personal devices

Likewise, for personal devices (eg, mobile phones, tablets) no legislative requirements explicitly refer to any EMF exposure limits. Although the Consumer Guarantees Act 1993 requires goods sold to the public to be 'safe' (which in this situation could be taken to mean 'exposures comply with limits recommended by the Ministry of Health'), in practice the onus would be on the consumer to commission tests of devices that were considered not to comply with the limits, which is a very expensive exercise. A similar situation would apply if action were taken under the Fair Trading Act 1986 (eg, if a consumer believed that SAR claims made for a phone were false).

The Ministry of Consumer Affairs has the power to mandate product safety standards under the Fair Trading Act. However, it takes the view that in specialist areas such as this, it is preferable for agencies that are more directly involved to develop and implement controls, should they be considered necessary.

Whether specific controls are necessary is debatable. Most major markets (eg, the USA, Europe, Australia, China, India) do mandate SAR limits and require evidence of compliance from accredited test laboratories, so in practice it is highly unlikely that manufacturers would produce phones that do not comply. In addition, the three mobile phone network operators in New Zealand either require evidence that phones they sell comply with SAR limits or that this information is maintained in a compliance folder by their suppliers. In other words, non-regulatory means are currently achieving the desired end.

The SAR values reported for devices are worst-case values, based on the assumptions that devices connected to a mobile phone network transmit at maximum power and that devices using WiFi transmit continuously. The actual SAR when devices are in use is invariably quite different to the reported value, due to the adaptive power control used in mobile networks and the WiFi duty cycle. 'Drive tests', which involved taking mobile phones on a fixed route around a city, have found that network characteristics are more important in determining exposures than the SAR value (Kuhn and Kuster 2012). Hence reported SAR values should generally be taken as indicating whether or not a device can be guaranteed to comply with SAR limits under all circumstances, rather than as a meaningful comparative measure of exposures when in use.

## 6.2 New technologies

This section discusses new RF technologies, especially those that have aroused some public interest, and how they might affect exposures.

# New technologies and frequencies on mobile phone networks

## 4G/LTE

All three mobile phone networks operating in New Zealand have introduced 4G/LTE<sup>18</sup> and new frequencies over the past few years. The introduction of 4G/LTE is driven by the need for increased data capacity (around 80–90% increase per year over the past five years) and delivery rates. 4G makes more efficient use of the radio spectrum, allowing more data to be sent using the same transmitter power. Thus while the addition of 4G transmitters to a mobile phone site generally increases the exposure, the increase is less than it would have been if extra 3G transmitters had been added to provide the same additional capacity.

Data from several countries shows that base stations never transmit at their maximum possible power, on any of the technologies (2G, 3G or 4G) installed. Typically the median transmit power for a site with all three technologies is less than a quarter of the maximum possible, and 95% of the time the transmit power is less than one-third of the maximum possible.

As with previous mobile phone technologies, mobile phones and other devices communicating over a 4G/LTE mobile phone network use adaptive power control to reduce their power (and hence the exposures they produce) to be just sufficient to maintain the link. The efficiency of power control in 3G phones and devices is well established, and transmit powers during a voice call are typically 100 times lower than the maximum possible. Data on 4G/LTE phones and other mobile devices shows that they too typically transmit at an average power around 100 times lower than the maximum possible.

Independent monitoring commissioned by all three New Zealand operators has found that exposures in public areas near cell sites are generally well below 1% of (ie, over 100 times lower than) the public limit in NZS 2772.1:1999. Maximum possible levels are also normally no more than a few percentage points of the limit.

## 5G

The next generation of mobile services, usually referred to as 5G, will address consumer needs for higher data rates and capacity, and lower latency (effectively 'dead time' in transmitting messages). Its commercial introduction is expected in 2020, with limited test installations operating before then. Initially 5G services will use frequencies of around 3.5 GHz, but higher frequencies of around 26 GHz (sometimes referred to as millimetre waves – mmWaves) will be introduced later, especially where high data rates or capacity are needed. A Radio Spectrum Management discussion document, published in March 2018 (RSM 2018) envisages that other frequency bands (around 1.4 GHz and 600 MHz) may also be used in the longer term. Existing health effects research already covers all these frequency bands, and they are also covered in the

<sup>18</sup> 4G = fourth generation; LTE = long term evolution.

New Zealand Standard for RF field exposure. Millimetre waves are already widely used for point-to-point communication links.

The modulation scheme (the way the data is encoded onto the radio signal) is similar to that used in 4G, and initially existing 4G networks will provide the control signalling between cell sites and user devices, while data is transferred over the 5G carriers. Instead of transmitting fixed radio beams that cover a 120-degree-wide sector like current technology, 5G antennas will produce a large number of discrete radio beams that each cover a much smaller area, and are powered up and directed where and when they are needed (and turned off when not needed). In other words, when a user is downloading data from one of these antennas, the radio signal carrying the data is directed towards that user and does not spread out over a wide area – mostly in directions where it is not needed – as it would at the moment, and that beam is turned off when the data has been transferred.

Not much information is available at the moment on how 5G deployment might affect exposures. Results from a test installation in Australia suggest that the addition of 5G would be similar to adding another 3G or 4G carrier. As with current-generation mobile technologies, the transmitter power is adjusted continuously so as to be just sufficient to handle traffic through the site and this approach, combined with the finer beam-forming capabilities described above, leads to theoretical estimates that average transmitter power will be no more than 25% of the maximum possible.

There have been some concerns that use of the higher frequencies, which are poorly transmitted through buildings, will require sites to be much more closely spaced than they are now in order to provide adequate coverage, and that this could lead to much higher exposures than at present. In practice, if sites are spaced closely together they will each operate at much lower powers than a single large site covering a wider area, and exposures would be similar to what they are at present. Such deployments are more likely in areas with a high user density, such as city centres, rather than residential suburbs. 5G sites operating at any frequency will still have to meet the requirements of the NESTF (see 'Environmental exposures' in Section 6.1).

At 26 GHz, almost all of the power in a radio signal is absorbed in the skin, so the exposure (both the basic restriction and reference level) is normally quantified in terms of the incident power flux density (and SAR is not relevant). This creates new challenges in quantifying exposures from hand-held devices (mobile phones, tablets etc), as existing test standards cover SAR measurement, but not power flux density. The International Electrotechnical Commission and IEEE, who have jointly developed the existing test standards, have prepared a technical review that forms the basis of a standard for evaluating exposures from devices against power flux density limits.

The imminent introduction of 5G services has also required a review of the transition in basic restrictions in exposure standards from SAR-based to those based on power flux density. ICNIRP has recently released a draft revision of its RF exposure limits to address this, and also has used recent research to review the time and spatial averaging provisions at frequencies above 6 GHz.

## Smart meters

Electricity retailers are progressively introducing smart meters (otherwise known as 'advanced metering infrastructure') throughout the country. Smart meters include a radio communication link, which allows them to be read remotely. Some also incorporate 'home area network' capability, through which they can control 'smart' appliances (eg, to turn them on at times of the day when electricity prices are lower), although this capability has not yet been activated.

Smart meters installed in New Zealand communicate in one of two ways.

- On the mobile phone network – these meters normally send their data once per day, in the early morning. The rest of the day they do not transmit, apart from brief 'handshakes' with the mobile phone network every hour or two.
- Via a 'mesh' network – meters transfer data back to access points (also called data concentrators), which may be mounted on power poles or lamp-posts, or inside a meter box. Normally the data is transferred from one meter to another, to another, until it arrives at the access point. The routing is automatically optimised by the network. In mesh networks, a meter transmits not only when sending its own data, but also when relaying data from other meters in the network back to the access point.

The transmitters in both types of meter operate intermittently and at low power. Measurements in New Zealand and overseas show that meters on mesh networks typically transmit for less than two minutes per day. Meters on mesh networks transmit at powers between about 0.1 and 1 watt (depending on the system being used), while meters communicating over the mobile phone network use a standard mobile phone module.

In practice, then, exposures from smart meters are very low because of:

- the relatively low power of the transmitter
- the intermittent nature of the transmissions
- the practice of mounting most meters on an outside wall (which means that exposures inside a house are attenuated by the meter box and the house wall).

Measurements on the inside of a wall behind a smart meter in Hamilton showed that the maximum exposure while the meter was transmitting was 0.18% (about one five-hundredth) of the public limit in NZS 2772.1:1999 (Gledhill 2012). The highest exposure averaged over 30 seconds (bearing in mind that the standard allows exposures to be averaged over six minutes) was 0.003% of the public limit.

Access points (or data concentrators) also operate at low power and produce very low exposures.

## WiFi

Many modern devices establish network communications over WiFi (indeed, many have no capability for a wired network connection). WiFi protocols have evolved over the years to allow faster data transmission rates, but the essential characteristics have not changed.

In a simple WiFi setup, the access point (or wireless router) acts as the connecting point between nearby WiFi devices and a wired network. For the system to work, only one device (or the access point) can communicate at a time, and mechanisms are built in to the WiFi protocols to try to enforce this. The access point periodically transmits a brief signal to alert nearby devices that it is available if needed. Apart from that, the devices or access point only transmit when there is data to send.<sup>19</sup>

The maximum transmit power of access points and WiFi devices is limited by radio spectrum management rules. Tests carried out by the UK Health Protection Agency (now Public Health England) found that the transmit power of access points used in UK schools ranged from 3 to 29 mW, and the transmit power of laptops used in UK schools from 4 to 17 mW (Health Protection Agency 2012, Appendix 1). (For comparison, the maximum transmit power of a 3G mobile phone is 125 mW, and the average power of a DECT cordless phone during a call is 10 mW.) Access points were found to transmit from between 36 seconds and 7 minutes per hour (and were silent the rest of the time) and laptops between 0.7 and 33 seconds per hour.

Tests in New Zealand schools commissioned by the Ministry of Health have confirmed that exposures from both access points and devices are very low, with a maximum exposure in classrooms equivalent to 0.024% of (ie, 4,000 times lower than) the public limit in the New Zealand Standard, and generally less than half that figure. Similar levels have been found overseas, including from a recent study in Australia (Karipidis et al 2017). The rollout of WiFi in New Zealand schools has largely proceeded without any problems. A few specialised schools have chosen to limit the use of WiFi, but state schools have put in no restrictions.

A few countries (eg, Germany) recommend using wired connections in schools if a choice is available, but many others state that there are no reasons to limit use of WiFi in schools. Sometimes it is suggested that some countries (eg, Switzerland) or regions (eg, Bavaria) have banned the use of WiFi in schools, but follow-up with the relevant authorities has found that they have not done so. The Ministry of Health suggests that if people wish to reduce exposures from WiFi, they can place access points on a high shelf or high up on a wall, and WiFi-enabled devices could be used on a table rather than in the lap.

This discussion on exposures from WiFi has largely focused on the use of WiFi in schools because that has been an area of particular interest. However, the results would apply equally to the use of WiFi in other settings, such as in the home or workplace.

<sup>19</sup> Some devices may also issue 'probe' signals to find nearby access points.

## Wireless power transfer

Wireless power transfer (WPT) is a rapidly developing technology finding increasing applications in various areas. Although most people are only familiar with its use for recharging mobile phones and other small appliances, there are systems that allow much higher powers to be transferred over short distances in order to, for example, provide electrical isolation or to recharge electric vehicle batteries. WPT uses inductive coupling between the power source and the load (similar to the principle used in a transformer, but without the need for a core), and requires the source and load to be quite close together. Frequencies used vary from around 100 kHz to a few MHz.

The safety of such systems has been closely investigated. An extremely conservative assessment is to measure the magnetic fields produced by WPT systems and compare these against reference levels. For a vehicle charging system, for example, that transfers several kW of power with a source-load separation of up to 30 cm,<sup>20</sup> the region within which magnetic fields exceed the reference levels extends well beyond the vehicle. Computer modelling of how the body interacts with the fields, however, shows that for someone kneeling by the vehicle, or extending an arm between the source and load coils, exposures comply with the basic restrictions. A lot of work is going on to develop testing standards that provide a realistic compliance assessment without having to resort to detailed computer models every time.

## Internet of Things

The Internet of Things will see greater use of wireless technologies to link a wide variety of devices to exchange data and allow remote control. It will largely use existing wireless technologies (eg, WiFi, mobile phone networks) to provide the links. Although some applications will be data intensive, others (eg, control of street lamps, reading water meters) will use low-power, low-capacity networks where there is need for only occasional low-rate connectivity, sometimes over large distances. Several New Zealand companies are developing networks, or have announced plans to do so, for such low data rate applications. The RF exposure levels are low due to the low transmission power and very short transmission time.

## Others

The use of 'machine to machine' (M2M) communication, often drawing on mobile phone technologies, has grown rapidly. Current applications include, for example, food and drink dispensers, lift controllers, mussel farms and restaurant fridges. Often people are not aware that such systems are in use. Wearable wireless technologies are also being developed (eg, for health monitoring) using either Bluetooth or other low-power technologies. While existing safety standards cover these applications, it is important to keep up to date with developments in this area, and how exposures can be readily assessed, to ensure that health protection is not overlooked.

<sup>20</sup> Vehicle charging systems have the supply coils just under the ground surface, and the receiver coils beneath the vehicle.

## 6.3 How EMF health issues are handled in New Zealand

### Ministry of Health acts as lead agency

The Ministry of Health acts as lead agency in all matters concerning EMF and health. In this capacity, it has advised, for example, the Ministry of Education on health aspects of WiFi in schools, and the Ministry for the Environment on suitable health-based standards to be applied in National Environmental Standards on radio transmitters and transmission lines. The Ministry also advises WorkSafe.

In undertaking this work, the Ministry relies on the public health expertise of its own staff, but can also call on the more specialised knowledge of external providers where necessary. Two important external sources of information are discussed in more detail below.

The Ministry has several pages on its website to provide EMF information.<sup>21</sup> These include links to other sources of information. The Ministry website also contains links to recent research reviews carried out by national and international health and scientific bodies.<sup>22</sup> These pages are updated as new reports and information become available.

The Ministry does not fund or commission EMF research. Funding is the responsibility of the Health Research Council, which, as noted in Section 4.7, has provided money for the New Zealand arm of the international MOBI-Kids study. The Ministry would advise the Health Research Council (or other funding bodies) on EMF research priorities if asked. This advice would be based on documents such as the Research Agendas prepared by the WHO EMF Project (see below).

### WHO EMF Project

The WHO established its EMF Project in 1996 to coordinate research, identify areas where further research is needed, publish authoritative health risk assessments in the WHO's Environmental Health Criteria (EHC) series, and facilitate the development of internationally acceptable exposure standards. In recent years it has published monographs in its EHC series on static fields (EHC 232) and ELF fields (EHC 238), and is preparing a monograph on RF fields. Members of the task group responsible for the final publication must cover the required range of expertise and are also selected to ensure a balance of the range of opinions, geographical distribution and gender. Task group members must also comply with strict WHO rules on conflicts of interest.

<sup>21</sup> See the links from [www.health.govt.nz/our-work/radiation-safety/non-ionising-radiation](http://www.health.govt.nz/our-work/radiation-safety/non-ionising-radiation)

<sup>22</sup> See [www.health.govt.nz/our-work/radiation-safety/non-ionising-radiation/research-non-ionising-radiation](http://www.health.govt.nz/our-work/radiation-safety/non-ionising-radiation/research-non-ionising-radiation)

New Zealand has long recognised the value offered by this international collaboration, which is funded entirely by ad hoc contributions from member states (ie, it does not receive any funding from the WHO), and has been one of the few consistent contributors to the project. (Some countries have made contributions in kind; for example, by making staff available to work at the WHO.) The quality of the material produced by the project has far exceeded what would have been possible if New Zealand had chosen to try to develop it independently.

For further information, visit the WHO website: [www.who.int/peh-emf/en/](http://www.who.int/peh-emf/en/)

## Interagency Committee on the Health Effects of Non-ionising Fields

The Interagency Committee on the Health Effects of Non-Ionising Fields was originally established in 1989 by the then Ministry of Economic Development to monitor and review research on the health effects of ELF fields. The scope was extended to include RF fields in 2001, at which time it became a Ministry of Health technical advisory committee. Its current terms of reference and members are presented in Appendix F.

The sectors and government agencies represented on the Committee are invited by the Director-General of Health. Government agencies and industry sectors nominate their own representatives, but representatives for other sectors are approached by the Ministry on the basis of their knowledge and experience in the area and ability to represent the sector.

A key function of the Committee is to review recent research findings, and especially recent research reviews published by national and international health and scientific bodies, to determine whether it should recommend any changes to current policies. Contributions from the academic representatives are especially valuable in this respect. The Committee provides its advice to the Director-General of Health and its advice forms one input into Ministry of Health policy in this area.

While there is sometimes public concern over the presence of industry representatives on the Committee, in practice they have never attempted to influence the Committee's conclusions on the health effects research, and generally see the Committee as a means for them to stay abreast of recent developments. In addition, they are able to bring to the Committee's attention forthcoming developments in their industries that may have policy implications for Government.

## 6.4 Key EMF research carried out in New Zealand

New Zealand researchers have been, or are, involved in several large research projects investigating EMF and health. In addition to these major projects, individuals and small research teams at other New Zealand universities (including Auckland, Massey and Victoria) have also published EMF research.

### University of Otago study on ELF fields and childhood leukaemia

The University of Otago considered ELF fields as part of a large epidemiological study into childhood leukaemia. ELF fields were measured over a 24-hour period in the homes of the children with cancer and comparison children, and information was obtained about the children's exposure to electrical appliances. The study was designed to be compatible with similar studies being carried out at the same time in other countries (including Canada, the UK and the USA) so that, as well as being published independently (Dockerty et al 1998), the results could be combined in meta-analyses (Ahlbom et al 2000; Greenland et al 2000).

### New Zealand arm of the Interphone study

Researchers from the University of Auckland participated in the Interphone study (see Section 4.2) and coordinated its New Zealand arm. In addition to identifying and interviewing cases and controls in New Zealand, the researchers collaborated in the various studies to develop and validate the Interphone methodology.

### New Zealand arm of the MOBI-Kids study

The Massey University Centre for Public Health Research is currently coordinating the New Zealand arm of the MOBI-Kids study. As discussed in Section 4.7, this is a multinational study that builds on the experience gained through the Interphone research to investigate potential associations between mobile phone use and brain tumours in young people (aged 10–24 years). The first findings are expected to be published shortly.

## New Zealand participation in Interocc

The Massey University Centre for Public Health Research has participated in the Interocc study, which uses data acquired during the Interphone study to investigate possible causes of brain tumours and a number of agents encountered in occupational settings (such as magnetic fields, solvents and combustion products). While there were one or two statistically significant findings in relation to EMF exposures, none was considered particularly convincing. The data has also been used to establish a job-exposure matrix, which will be valuable in future occupational studies.

# References

AFSSET (Agence française de sécurité sanitaire de l'environnement et du travail [French Agency for Environmental and Occupational Health Safety]). 2009. *Mise à jour de l'expertise relative aux radiofréquences. Rapport d'expertise collective*. Saisine #2007/007.

Ahlbom A, Day N, Feychting M, et al. 2000. A pooled analysis of magnetic fields and childhood leukaemia. *British Journal of Cancer* 83(5): 692–8.

Amoon A, Crespi C, Ahlborn A, et al. 2018. Proximity to overhead power lines and childhood leukaemia: an international pooled analysis. *British Journal of Cancer* 119(3): 364–73.

ANSES. 2013. *Radiofréquences et santé: Mise à jour de l'expertise: Avis de l'Anses: Rapport d'expertise collective*. Maisons-Alfort: Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail. Full report (in French) URL: [www.anses.fr/sites/default/files/documents/AP2011sa0150Ra.pdf](http://www.anses.fr/sites/default/files/documents/AP2011sa0150Ra.pdf) (accessed 17 October 2018). English translation of the summary of findings of the expert group, and the ANSES opinion, URL: <https://www.anses.fr/en/system/files/AP2011sa0150RaEN.pdf> (accessed 24 October 2018).

ANSES. 2016. *Exposition aux radiofréquences et santé des enfants: Avis de l'Anses: Rapport d'expertise collective*. Maisons-Alfort: Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail. Full report (in French) URL: [www.anses.fr/fr/content/exposition-des-enfants-aux-radiofr%C3%A9quences-pour-un-usage-mod%C3%A9r%C3%A9-et-encadr%C3%A9-des-technologies](http://www.anses.fr/fr/content/exposition-des-enfants-aux-radiofr%C3%A9quences-pour-un-usage-mod%C3%A9r%C3%A9-et-encadr%C3%A9-des-technologies) (accessed 17 October 2018). English translation of the summary of findings of the expert group, and the ANSES opinion, URL: [www.anses.fr/en/system/files/AP2012SA0091EN.pdf](http://www.anses.fr/en/system/files/AP2012SA0091EN.pdf) (accessed 17 October 2018).

ANSES. 2018. *Hypersensibilité électromagnétique ou intolérance environnementale idiopathique attribuée aux champs électromagnétiques. Avis de l'Anses. Rapport d'expertise collective*. Maisons-Alfort: Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail. Full report (in French). URL: <https://www.anses.fr/fr/system/files/AP2011SA0150Ra.pdf> (accessed 17 October 2018). English translation of the summary of findings of the expert group, and the ANSES opinion, URL: <https://www.anses.fr/en/system/files/AP2011SA0150EN.pdf> (accessed 17 October 2018).

ARPANSA. 2002. *Maximum Exposure Levels to Radiofrequency Fields – 3 kHz to 300 GHz*. Radiation protection series publication no. 3. Melbourne: Australian Radiation Protection and Nuclear Safety Agency.

ARPANSA. 2017. *Radiofrequency Electromagnetic Energy and Health: Research needs*. Technical Report 178. Melbourne. Australian Radiation Protection and Nuclear Safety Agency.

ARPANSA Radiofrequency Expert Panel. 2014. *Report by the ARPANSA Radiofrequency Expert Panel on Review of Radiofrequency Health Effects Based on Scientific Literature 2000–2012*. Technical Report Series no 164. Yallambie: Australian Radiation Protection and Nuclear Safety Agency. URL:

<https://www.arpansa.gov.au/sites/g/files/net3086/f/legacy/pubs/technicalreports/tr164.pdf> (accessed 24 October 2018)

Aydin D, Feychting M, Schuz J, et al. 2011. Mobile phone use and brain tumors in children and adolescents: a multicenter case-control study. *Journal of the National Cancer Institute* 103: 1–13.

Baan R, Grosse Y, Lauby-Secretan B, et al. 2011. Carcinogenicity of radiofrequency electromagnetic fields. *Lancet* 12(7): 624–6.

Baliatsas C, Van Kamp I, Bolte J, et al. 2012. Non-specific physical symptoms and electromagnetic field exposure in the general population: can we get more specific? A systematic review. *Environment International* 41: 15–28.

Benson V, Pirie K, Schuz J, et al. 2013a. Authors' response to: the case of acoustic neuroma: comment on mobile phone use and risk of brain neoplasms and other cancers. *International Journal of Epidemiology* epub 10.1093.

Benson V, Pirie K, Schuz J, et al. 2013b. Mobile phone use and risk of brain neoplasms and other cancers: prospective study. *International Journal of Epidemiology* 42(3): 792–802.

Berg-Beckhoff G, Blettner M, Kowall B, et al. 2009. Mobile phone base stations and adverse health effects: phase 2 of a cross-sectional study with measured radio frequency electromagnetic fields. *Occupational and Environmental Medicine* 66: 124–30.

Bhatt C, Benke G, Smith C, et al. 2017. Use of mobile and cordless phones and change in cognitive function: a prospective cohort analysis of Australian primary school children. *Environmental Health* 16:62 DOI 10.1186/s12940-017-0250-4.

BioInitiative Report. 2007. *Biologically-based Exposure Standards for Low-intensity Electromagnetic Radiation* (with updates 2012, 2014, 2017). URL: [www.bioinitiative.org](http://www.bioinitiative.org) (accessed 14 October 2018).

Buchner K, Eger H. 2011. Changes of clinically important neurotransmitters under the influence of modulated RF fields: a long-term study under real-life conditions. *Umwelt-Medizin-Gesellschaft* 24: 44–57. [Original study in German.]

Bunch K, Keegan T, Swanson J, et al. 2014. Residential distance at birth from overhead high-voltage powerlines: childhood cancer risk in Britain 1962–2008. *British Journal of Cancer* 110(5): 1402–8.

Bunch K, Swanson J, Vincent T, et al. 2015. Magnetic fields and childhood cancer: an epidemiological investigation of the effects of high-voltage underground cables. *Journal of Radiological Protection* 35(3): 695–705.

Bunch K, Swanson J, Vincent T, et al. 2016. Epidemiological study of power lines and childhood cancer in the UK: further analyses. *Journal of Radiological Protection* 36(3): 437–55.

Chapman S, Azizi L, Luo Q, et al. 2016. Has the incidence of brain cancer risen in Australia since the introduction of mobile phones 29 years ago? *Cancer Epidemiology* 42: 199–205.

Chen Q, Lang L, Wu W, et al. 2013. A meta-analysis on the relationship between exposure to ELF-EMFs and the risk of female breast cancer. *PLoS One* 8(7): e69272.

COMAR (Committee on Man and Radiation). 2009. COMAR technical information statement: expert reviews on potential health effects of radiofrequency electromagnetic fields and comments on the Bioinitiative Report. *Health Physics* 97(4): 348–56.

Council of the EU. 1999. Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz). *Official Journal of the European Union* L 199: 59–70. URL: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1999:199:0059:0070:EN:PDF> (accessed 15 October 2018).

Crespi CM, Vergara XP, Hooper C, et al. 2016. Childhood leukaemia and distance from power lines in California: a population-based case-control study. *British Journal of Cancer* 115(1): 122–8.

Danker-Hopfe H, Dorn H, Bornkessel C, et al. 2010. Do mobile phone base stations affect sleep of residents? Results from an experimental double-blind sham-controlled field study. *American Journal of Human Biology* 22(5): 613–18.

de Vocht F. 2016. Inferring the 1985–2014 impact of mobile phone use on selected brain cancer subtypes using Bayesian structural time series and synthetic controls. *Environment International* 97: 100–7.

de Vocht F, Burstyn I, Cherrie J. 2011. Time trends (1998–2007) in brain cancer incidence rates in relation to mobile phone use in England. *Bioelectromagnetics* 32(5): 334–9.

de Vocht F, Olsen R. 2016. Systematic review of the exposure assessment and epidemiology of high-frequency voltage transients. *Frontiers in Public Health* 4: 52.

Deltour I, Auvinen A, Feychting M, et al. 2012. Mobile phone use and incidence of glioma in the Nordic countries 1979–2008: consistency check. *Epidemiology* 23(2): 301–7.

Demers P, Findlay R, Foster K, et al. 2014. *Expert Panel Report on a Review of Safety Code 6: Health Canada's safety limits for exposure to radiofrequency fields*. Ottawa: Royal Society of Canada. URL: [https://rsc-src.ca/sites/default/files/SC6\\_Report\\_Formatted\\_1.pdf](https://rsc-src.ca/sites/default/files/SC6_Report_Formatted_1.pdf) (accessed 15 October 2018).

Directorate-General for Employment, Social Affairs and Inclusion. 2016. *Non-binding Guide to Good Practice for Implementing Directive 2013/35/EU Electromagnetic Fields. Volumes 1–3*. Luxembourg: Publications Office of the European Union. URL: <https://osha.europa.eu/en/legislation/guidelines/non-binding-guide-good-practice-implementing-directive-201335eu> (accessed 15 October 2018).

Dockerty J, Elwood M, Skegg D, et al. 1998. Electromagnetic field exposures and childhood cancers in New Zealand. *Cancer Causes and Control* 9: 299–309. Erratum in 1999; 10: 641.

Draper G, Vincent T, Kroll M, et al. 2005. Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case-control study. *British Medical Journal* 330: 1290.

EFHRAN. 2012. *Risk Analysis of Human Exposure to Electromagnetic Fields*. Revised version. Deliverable Report D2 of EHFRAN project.

Elwood J. 2014. Mobile phones, brain tumors, and the limits of science. *Bioelectromagnetics* 35(5): 379–83.

EMF-NET. 2007. *Comments on the BioInitiative Working Group Report (BioInitiative Report)*. EMF-NET Coordination Action. European Commission, Brussels.

Eskander E, Estefan S, Abd-Rabou A. 2012. How does long term exposure to base stations and mobile phones affect human hormone profiles? *Clinical Biochemistry* 45: 157–61.

Feychting M. 2013. Invited commentary: extremely low-frequency magnetic fields and breast cancer – now it is enough! *American Journal of Epidemiology* 178(7): 1046–50.

Foster K, Chou C. 2014. Are children more exposed to radiofrequency energy from mobile phones than adults? *IEEE Access*. DOI: 10.1109/ACCESS.2014.2380355.

Frei P, Poulsen A, Johansen C, et al. 2011. Use of mobile phones and risk of brain tumours: update of Danish cohort study. *British Medical Journal* 343: d6387. DOI: 10.1136/bmj.d6387.

Gledhill M. 2012. *Measurements of Radiofrequency Fields from a WEL Networks Smart Meter*. Report 2012/36. Hamilton: WEL Networks Ltd. URL: [www.wel.co.nz/UserFiles/WeiNetworks/File/RF%20fields%20from%20a%20WEL%20Networks%20Smart%20Meter.pdf](http://www.wel.co.nz/UserFiles/WeiNetworks/File/RF%20fields%20from%20a%20WEL%20Networks%20Smart%20Meter.pdf) (accessed 15 October 2018).

Greenland S, Sheppard A, Kaune W, et al. 2000. A pooled analysis of magnetic fields, wire codes, and childhood leukaemia. *Epidemiology* 11(6): 624–34.

Health Canada. 2015. *Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz – Safety Code 6*. Ottawa: Health Canada. URL: [www.hc-sc.gc.ca/ewh-semt/consult/\\_2014/safety\\_code\\_6-code\\_securite\\_6/final\\_finale-eng.php](http://www.hc-sc.gc.ca/ewh-semt/consult/_2014/safety_code_6-code_securite_6/final_finale-eng.php) (accessed 17 October 2018).

Health Council of the Netherlands. 2008. *Letter to the Minister of Housing, Spatial Planning and the Environment (VROM)*. Publication 2008/17E (2008). URL: <https://www.healthcouncil.nl/documents/advisory-reports/2008/09/02/bioinitiative> (accessed 24 October 2018).

Health Council of the Netherlands. 2011. *Influence of Radiofrequency Telecommunications Signals on Children's Brains*. Publication no. 2011/20E. The Hague: Health Council of the Netherlands. URL: <https://www.healthcouncil.nl/documents/advisory-reports/2011/10/18/influence-of-radiofrequency-telecommunication-signals-on-children%E2%80%99s-brains> (accessed 24 October 2018).

- Health Council of the Netherlands. 2013. *Mobile Phones and Cancer: Part 1: Epidemiology of tumours of the head*. Publication no. 2013/11. The Hague: Health Council of the Netherlands. URL: <https://www.healthcouncil.nl/documents/advisory-reports/2013/06/03/mobile-phones-and-cancer-part-1-epidemiology-of-tumours-in-the-head> (accessed 24 October 2018).
- Health Council of the Netherlands. 2014. *Mobile Phones and Cancer: Part 2: Animal studies on carcinogenesis*. Publication no. 2014/22. The Hague: Health Council of the Netherlands. URL: <https://www.healthcouncil.nl/documents/advisory-reports/2014/09/05/mobile-phones-and-cancer-part-2-animal-studies-on-carcinogenesis> (accessed 28 October 2018).
- Health Council of the Netherlands. 2016. *Mobile Phones and Cancer: Part 3: Update and overall conclusions from epidemiological and animal studies*. Publication no. 2016/16. The Hague: Health Council of the Netherlands. URL: <https://www.healthcouncil.nl/documents/advisory-reports/2016/06/01/mobile-phones-and-cancer-part-3-update-and-overall-conclusions-from-epidemiological-and-animal-studies> (accessed 24 October 2018).
- Health Council of the Netherlands. 2018. *Power Lines and Health Part I: Childhood cancer*. No. 2018/08. The Hague: Health Council of the Netherlands. URL: [https://www.healthcouncil.nl/binaries/healthcouncil/documents/advisory-reports/2018/04/18/power-lines-and-health-part-i-childhood-cancer/executive\\_summary\\_power\\_lines\\_and\\_health\\_part\\_i\\_childhood\\_cancer.pdf](https://www.healthcouncil.nl/binaries/healthcouncil/documents/advisory-reports/2018/04/18/power-lines-and-health-part-i-childhood-cancer/executive_summary_power_lines_and_health_part_i_childhood_cancer.pdf) (accessed 24 October 2018).
- Health Protection Agency. 2012. *Health Effects from Radiofrequency Electromagnetic Fields: Report of the Independent Advisory Group on Non-ionising Radiation: RCE-20*. London: Health Protection Agency. URL: [www.gov.uk/government/publications/radiofrequency-electromagnetic-fields-health-effects](http://www.gov.uk/government/publications/radiofrequency-electromagnetic-fields-health-effects) (accessed 17 October 2018).
- Heinrich S, Thomas S, Heumann C, et al. 2010. Association between exposure to radiofrequency electromagnetic fields assessed by dosimetry and acute symptoms in children and adolescents: a population based cross-sectional study. *Environmental Health* 9: 75.
- Hill A. 1965. The environment and disease: association or causation? *Proceedings of the Royal Society of Medicine* 58(5): 295–300. URL: [www.ncbi.nlm.nih.gov/pmc/articles/PMC1898525/](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1898525/) (accessed 17 October 2018).
- Huss A, Koeman T, Kromhout H, et al. 2015. Extremely low frequency magnetic field exposure and Parkinson's disease: a systematic review and meta-analysis of the data. *International Journal of Environmental Research and Public Health* 12(7): 7348–56.
- ICNIRP (International Commission on Non-Ionizing Radiation Protection). 1998. Guidelines for limiting exposure to time-varying electric and electromagnetic fields (up to 300 GHz). *Health Physics* 74(4): 494–522. URL: [www.icnirp.org](http://www.icnirp.org) (accessed 16 October 2018).
- ICNIRP. 2002. General approach to protection against non-ionizing radiation. *Health Physics* 82(4): 540–8. URL: [www.icnirp.org](http://www.icnirp.org) (accessed 16 October 2018).

ICNIRP. 2009a. *Exposure to High Frequency Electromagnetic Fields, Biological Effects and Health Consequences (100 kHz–300 GHz): Review of the scientific evidence and health consequences*. Munich: International Commission on Non-Ionizing Radiation Protection.

ICNIRP. 2009b. ICNIRP statement on 'Guidelines for limiting exposure to time-varying electric and electromagnetic fields (up to 300 GHz)'. *Health Physics* 97(3): 257–8. URL: [www.icnirp.org](http://www.icnirp.org) (accessed 16 October 2018).

ICNIRP. 2010. Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz–100 kHz). *Health Physics* 99(6): 818–36. URL: [www.icnirp.org](http://www.icnirp.org) (accessed 16 October 2018).

ICNIRP. 2017. Note on the revision of the high-frequency portion of the ICNIRP 1998 EMF Guidelines. URL: [www.icnirp.org/en/activities/news/news-article/revision-of-hf-guidelines-2017.html](http://www.icnirp.org/en/activities/news/news-article/revision-of-hf-guidelines-2017.html) (accessed 16 October 2018).

ICNIRP. 2018. ICNIRP note on recent animal carcinogenesis studies. URL: [www.icnirp.org/cms/upload/publications/ICNIRPnote2018.pdf](http://www.icnirp.org/cms/upload/publications/ICNIRPnote2018.pdf) (accessed 17 October 2018).

IEEE International Committee on Electromagnetic Safety (SCC39). 2005. *IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz*. New York: Institute of Electrical and Electronic Engineers. URL: [www.ices-emfsafety.org](http://www.ices-emfsafety.org) (accessed 17 October 2018).

IEEE Standards Coordinating Committee 28. 2007. *IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0–3 kHz*. New York: Institute of Electrical and Electronic Engineers. URL: [www.ices-emfsafety.org](http://www.ices-emfsafety.org) (accessed 17 October 2018).

Independent Expert Group on Mobile Phones. 2000. *Mobile Phones and Health*. Chilton: Independent Expert Group on Mobile Phones. URL: <http://webarchive.nationalarchives.gov.uk/20101011032547/http://www.iegmp.org.uk/> (accessed 14 October 2018).

Institution of Engineering and Technology. 2012. *Are There Harmful Biological Effects of Low-Level Electromagnetic Fields at Frequencies up to 300 Ghz? 2012 position statement provided by the Institution of Engineering and Technology*. London: Institution of Engineering and Technology.

Institution of Engineering and Technology. 2014. *Are There Harmful Biological Effects of Low-level Electromagnetic Fields at Frequencies up to 300 GHz? 2014 position statement provided by the Institution of Engineering and Technology*. London: Institution of Engineering and Technology. URL: [www.theiet.org/factfiles/bioeffects/emf-position-page.cfm](http://www.theiet.org/factfiles/bioeffects/emf-position-page.cfm) (accessed 17 October 2018).

Institution of Engineering and Technology. 2016. *Do low-level electromagnetic fields up to 300 GHz harm us?* Stevenage: Institution of Engineering and Technology. URL: [www.theiet.org/factfiles/bioeffects/emf-position-page.cfm](http://www.theiet.org/factfiles/bioeffects/emf-position-page.cfm) (accessed 17 October 2018).

Interagency Committee on the Health Effects of Non-ionising Fields. 2015. *Interagency Committee on the Health Effects of Non-ionising Fields: Report to Ministers*. Wellington: Ministry of Health.

- Interphone Study Group. 2010. Brain tumour risk in relation to mobile telephone use: results of the INTERPHONE international case-control study. *International Journal of Epidemiology* 39(3): 675–94.
- Interphone Study Group. 2011. Acoustic neuroma risk in relation to mobile telephone use: results of the INTERPHONE international case-control study. *Cancer Epidemiology* 35(5): 453–64.
- Karipidis K, Henderson S, Wijayasinghe D, et al. 2017. Exposure to radiofrequency electromagnetic fields from Wi-Fi in Australian schools. *Radiation Protection Dosimetry* 175(4): 432–9.
- Kheifets L, Ahlborn A, Crespi C, et al. 2010a. A pooled analysis of extremely low-frequency magnetic fields and childhood brain tumours. *American Journal of Epidemiology* 172: 752–61.
- Kheifets L, Ahlbom A, Crespi C, et al. 2010b. Pooled analysis of recent studies on magnetic fields and childhood leukaemia. *British Journal of Cancer* 103: 1128–35.
- Kim S, Ioannides S, Elwood J. 2015. Trends in incidence of primary brain cancer in New Zealand, 1995 to 2010. *Australian and New Zealand Journal of Public Health*. DOI: 10.1111/1753-6405.12338.
- Koeman T, Stottie P, Schouten L, et al. 2017. Occupational exposure and amyotrophic lateral sclerosis in a prospective cohort. *Occupational and Environmental Medicine* oemed-2016-103780. DOI: 10.1136/oemed-2016-103780.
- Kuhn S, Kuster N. 2012. Field evaluation of the human exposure from multiband, multisystem mobile phones. *IEEE Transactions on Electromagnetic Compatibility* 55(2): 275–87.
- Lagorio S, Roosli M. 2013. Mobile phone use and risk of intracranial tumors: a consistency analysis. *Bioelectromagnetics*. DOI: 10.1002/bem.21829.
- Leitgeb N, Schröttner J, Cech R, et al. 2008. EMF-Protektions-Schlafstudie in der Nähe von Mobilfunk-Basisstationen. (EMF-protection sleep study near mobile phone base stations). *Somnologie (Somnology)* 12(3): 234–43.
- Lerchl A, Klose M, Grote K, et al. 2015. Tumor promotion by exposure to radiofrequency electromagnetic fields below exposure limits for humans. *Biochemical and Biophysical Research Communications* 459(4): 585–90.
- Li W, Thomas D, Yost M, et al. 2013. Occupational exposure to magnetic fields and breast cancer among women textile workers in Shanghai, China. *American Journal of Epidemiology* 178(7): 1038–45.
- Little M, Rajaraman P, Curtis R, et al. 2012. Mobile phone use and glioma risk: comparison of epidemiological study results with incidence trends in the United States. *British Medical Journal* 344: e1147. DOI: 10.1136/bmj.e1147.
- Loughran S, Hossain S, Bentvelzen A, et al. 2016. Bioelectromagnetics research within an Australian context: the Australian Centre for Electromagnetic Bioeffects Research (ACEBR). *International Journal of Environmental Research and Public Health* 13: 967.

- McKinlay A, Vecchia P, Ziegelberger G, et al (eds). 2011. Non-Ionizing Radiation (NIR) and Children's Health: Scientific proceedings of a conference held in Ljubljana, Slovenia, 18–20 May 2011. *Progress in Biophysics and Molecular Biology* 107(3): 311–482.
- Mild K, Repacholi M, van Deventer E, et al (eds). 2006. *Electromagnetic Hypersensitivity: Proceedings, International Workshop on Electromagnetic Field Hypersensitivity, Prague, Czech Republic, 25–27 October 2004*. URL: [www.who.int/peh-emf/publications/reports/EHS\\_Proceedings\\_June2006.pdf?ua=1](http://www.who.int/peh-emf/publications/reports/EHS_Proceedings_June2006.pdf?ua=1) (accessed 14 October 2018).
- Ministry of Health. 2013. *Electric and Magnetic Fields and Your Health: Information on electric and magnetic fields associated with transmission lines, distribution lines and electrical equipment*. Wellington: Ministry of Health.
- Mohler E, Frei P, Braun-Fahrlander C, et al. 2010. Effects of everyday radiofrequency electromagnetic-field exposure on sleep quality: a cross-sectional study. *Radiation Research* 174: 347–56.
- Mohler E, Frei P, Frohlich J, et al. 2012. Exposure to radiofrequency electromagnetic fields and sleep quality: a prospective cohort study. *PLoS One* 7(5): e37455.
- Nesslany F, Aurengo A, Bonnet-Belfais M, et al. 2015. Comment on Lerchl study: 'Tumor promotion in mice by exposure to radiofrequency electromagnetic fields still waiting evidence'. *Biochemical and Biophysical Research Communications* 467(1): 101–2.
- Norwegian Institute of Public Health. 2012. *Low Level Radiofrequency Electromagnetic Fields: An assessment of health risks and evaluation of regulatory practice*. Oslo: Norwegian Institute of Public Health. English translation of report summary URL: [www.fhi.no/dokumenter/545eea7147.pdf](http://www.fhi.no/dokumenter/545eea7147.pdf) (accessed 17 October 2018).
- NTP (National Toxicology Program). 2018a. *NTP Technical Report on Toxicology and Carcinogenesis Studies In B6C3F1/N Mice Exposed to Whole-Body Radio Frequency Radiation at a Frequency (1,900 MHz) and Modulations (GSM and CDMA) Used by Cell Phones (Draft)*. Technical Report TR 596: 1–270. Research Triangle Park, NC: National Institute of Environmental Health Sciences of the National Institutes of Health.
- NTP. 2018b. *NTP Technical Report on the Toxicology and Carcinogenesis Studies in Hsd:Sprague Dawley SD Rats Exposed to Whole-Body Radio Frequency Radiation at a Frequency (900 MHz) and Modulations (GSM and CDMA) Used by Cell Phones (Draft)*. Technical Report TR 595: 1-381. Research Triangle Park, NC: National Institute of Environmental Health Sciences of the National Institutes of Health.
- NTP. 2018c. *Peer Review of the Draft NTP Technical Reports on Cell Phone Radiofrequency Radiation*. Research Triangle Park, NC: National Institute of Environmental Health Sciences of the National Institutes of Health.
- Olsen JH, Nielsen A, Schulgen G. 1993. Residence near high voltage facilities and risk of cancer in children. *British Medical Journal* 307: 891–5.
- Pedersen C, Johansen C, Schüz J, et al. 2015. Residential exposure to extremely low-frequency magnetic fields and risk of childhood leukaemia, CNS tumour and lymphoma in Denmark. *British Journal of Cancer* 113: 1370–4.

- Repacholi M, Lerchl A, Roosli M, et al. 2012. Systematic review of wireless phone use and brain cancer and other head tumors. *Bioelectromagnetics* 33(3): 187–206.
- Repacholi M, Saunders R, van Deventer E, et al. 2005. Guest editors' introduction: is EMF a potential environmental risk for children? *Bioelectromagnetics* Suppl 7: S2–4.
- RSM. 2018. Preparing for 5G in New Zealand. Discussion Document. <https://www.rsm.govt.nz/projects-auctions/current-projects/preparing-for-5g-in-new-zealand/technical-consultation> (accessed 24 October 2018).
- Rubin G, Das Munshi J, Wessely S. 2005. Electromagnetic hypersensitivity: a systematic review of provocation studies. *Psychosomatic Medicine* 67: 224–32.
- Rubin G, Nieto-Hernandez R, Wessely S. 2010. Idiopathic environmental intolerance attributed to electromagnetic fields (formerly 'electromagnetic hypersensitivity'): an updated systematic review of provocation studies. *Bioelectromagnetics* 31: 1–11.
- Rubin G, Nieto-Hernandez R, Wessely S. 2011. Do people with idiopathic environmental intolerance attributed to electromagnetic fields display physiological effects when exposed to electromagnetic fields? A systematic review of provocation studies. *Bioelectromagnetics* 32(8): 593–609.
- Samet J, Straif K, Schuz J, et al. 2014. Mobile phones and cancer: next steps after the 2011 IARC review. *Epidemiology* 25(1): 23–7.
- SCENIHR (Scientific Committee on Emerging and Newly Identified Health Risks). 2012. *Memorandum on the Use of the Scientific Literature for Human Health Risk Assessment Purposes: Weighing of evidence and expression of uncertainty*. Luxembourg: European Commission. URL: [http://ec.europa.eu/health/scientific\\_committees/emerging/docs/scenihr\\_s\\_001.pdf](http://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_s_001.pdf) (accessed 17 October 2018).
- SCENIHR. 2015. *Potential Health Effects of Exposure to Electromagnetic Fields (EMF)*. Luxembourg: European Commission. URL: [http://ec.europa.eu/health/scientific\\_committees/consultations/public\\_consultations/scenihr\\_consultation\\_19\\_en.htm](http://ec.europa.eu/health/scientific_committees/consultations/public_consultations/scenihr_consultation_19_en.htm) (accessed 17 October 2018).
- Schmiedel S, Blettner M. 2010. The association between extremely low-frequency electromagnetic fields and childhood leukaemia in epidemiology: enough is enough? *British Journal of Cancer* 103: 931–2.
- Schoeni A, Roser K, Roosli M. 2015. Memory performance, wireless communication and exposure to radiofrequency electromagnetic fields: a prospective cohort study in adolescents. *Environment International* 85: 343–51.
- Schuz J, Dasenbrock C, Ravazzani P, et al. 2016. Extremely low-frequency magnetic fields and risk of childhood leukaemia: a risk assessment by the ARIMMORA Consortium. *Bioelectromagnetics* 37 (3):183–9.
- SSM Scientific Council on Electromagnetic Fields. 2013. *Eighth report from SSM's Scientific Council on Electromagnetic Fields, 2013*. Stockholm: Swedish Radiation Safety Authority. URL: <https://www.stralsakerhetsmyndigheten.se/publikationer/rapporter/stralskydd/2013/201319/> (accessed 24 October 2018).

SSM Scientific Council on Electromagnetic Fields. 2014. *Recent Research on EMF and Health Risk. Ninth report from SSM's Scientific Council on Electromagnetic Fields, 2014*. Stockholm: Swedish Radiation Safety Authority. URL: <https://www.stralsakerhetsmyndigheten.se/publikationer/rapporter/stralskydd/2014/201416/> (accessed 24 October 2018).

SSM Scientific Council on Electromagnetic Fields. 2015. *Recent Research on EMF and Health Risk. Tenth report from SSM's Scientific Council on Electromagnetic Fields, 2015*. Stockholm: Swedish Radiation Safety Authority. URL: [www.stralsakerhetsmyndigheten.se/Publikationer/Rapport/Stralskydd/2015/Recent-Research-on-EMF-and-Health-Risk-Tenth-report-from-SSMs-Scientific-Council-on-Electromagnetic-Fields-2015/](http://www.stralsakerhetsmyndigheten.se/Publikationer/Rapport/Stralskydd/2015/Recent-Research-on-EMF-and-Health-Risk-Tenth-report-from-SSMs-Scientific-Council-on-Electromagnetic-Fields-2015/) (accessed 17 October 2018).

SSM Scientific Council on Electromagnetic Fields. 2016. *Recent Research on EMF and Health Risk. Eleventh report from SSM's Scientific Council on Electromagnetic Fields, 2016. Including Thirteen years of electromagnetic field research monitored by SSM's Scientific Council on EMF and health: How has the evidence changed over time?* Stockholm: Swedish Radiation Safety Authority. URL: [www.stralsakerhetsmyndigheten.se/Publikationer/Rapport/Stralskydd/2016/201615-Recent-Research-on-EMF-and-Health-Risk/](http://www.stralsakerhetsmyndigheten.se/Publikationer/Rapport/Stralskydd/2016/201615-Recent-Research-on-EMF-and-Health-Risk/) (accessed 17 October 2018).

SSM Scientific Council on Electromagnetic Fields. 2018. *Recent research on EMF and health risk. Twelfth report from SSM's Scientific Council on Electromagnetic Fields, 2017*. Stockholm: Swedish Radiation Safety Authority. URL: [www.stralsakerhetsmyndigheten.se/contentassets/f34de8333acd4ac2b22a9b072d9b33f9/201809-recent-research-on-emf-and-health-risk](http://www.stralsakerhetsmyndigheten.se/contentassets/f34de8333acd4ac2b22a9b072d9b33f9/201809-recent-research-on-emf-and-health-risk) (accessed 17 October 2018).

Stam R. 2017. *Comparison of International Policies on Electromagnetic Fields (Power Frequency and Radiofrequency Fields)*. Bilthoven: National Institute for Public Health and the Environment.

Swedish Council for Working Life and Social Research. 2012. *Research During the Last Ten Years: Radiofrequency electromagnetic fields – Risk of disease and ill-health*. Stockholm: Swedish Council for Working Life and Social Research. URL: [www.fas.se/en/News/2012/10-years-of-research-on-the-health-risks-of-radiofrequency-fields/](http://www.fas.se/en/News/2012/10-years-of-research-on-the-health-risks-of-radiofrequency-fields/) (accessed 17 October 2018).

Thomas S, Kuhnlein A, Heinrich S, et al. 2008. Personal exposure to mobile phone frequencies and well-being in adults: a cross-sectional study based on dosimetry. *Bioelectromagnetics* 29: 463–70.

Thomas S, Heinrich S, von Kries R, et al. 2010. Exposure to radio-frequency electromagnetic fields and behavioural problems in Bavarian children and adolescents. *European Journal of Epidemiology* 25: 135–41.

Thuroczy G, Gajsek HI. 2011. *Report on the Level of Exposure (Frequency, Patterns and Modulation) in the European Union: Part 1: Radiofrequency (RF) radiation*. Deliverable report D4 of EFHRAN project.

Urbiniello D, Joseph W, Huss A, et al. 2014. Radio-frequency electromagnetic field (RF-EMF) exposure levels in different European outdoor urban environments in comparison with regulatory limits. *Environment International* 68: 49–54.

van Moorselaar I, Slottje P, Heller P, et al. 2016. Effects of personalised exposure on self-rated electromagnetic hypersensitivity and sensibility: a double-blind randomised controlled trial. *Environment International* 99: 255–62.

Vergara X, Kheifets L, Greenland S, et al. 2013. Occupational exposure to extremely low frequency magnetic fields and neurodegenerative disease: a meta-analysis. *Journal of Occupational and Environmental Medicine* 55(2): 135–46.

Vergara X, Mezei G, Kheifets L. 2015. Case-control study of occupational exposure to electric shocks and magnetic fields and mortality from amyotrophic lateral sclerosis in the US, 1991–1999. *Journal of Exposure Science and Environmental Epidemiology* 25(1): 65–71.

Verrender A, Loughran SP, Dalecki A, et al. 2016. Pulse modulated radiofrequency exposure influences cognitive performance. *International Journal of Radiation Biology* 92(10): 603–10.

Verrender A, Loughran S, Anderson V, et al. 2017. IEI-EMF provocation case studies: a novel approach to testing sensitive individuals. *Bioelectromagnetics* 39: 132–43.

WHO. 2007. *Environmental Health Criteria 238: Extremely low frequency fields*. Geneva: World Health Organization. URL: [www.who.int/peh-emf/publications/elf\\_ehc/en/index.html](http://www.who.int/peh-emf/publications/elf_ehc/en/index.html) (accessed 17 October 2018).

Wiedemann P, Schutz H, Borner F, et al. 2009. *Children's Health and RF EMF Exposure*. Jülich: Forschungszentrum Jülich GmbH. URL: <http://ro.uow.edu.au/cgi/viewcontent.cgi?article=1300&context=hbspapers> (accessed 17 October 2018).

Wiedemann P, Boerner F, Repacholi M. 2014. Do people understand IARC's 2B categorisation of RF fields from cell phones? *Bioelectromagnetics* 35(5): 373–8.

Yang M, Guo W, Yang C, et al. 2017. Mobile phone use and glioma risk: a systematic review and meta-analysis. *PLoS One* 12(5): e0175136. <https://doi.org/10.1371/journal.pone.0175136>.

Zhou H, Chen G, Chen C, et al. 2012. Association between extremely low frequency electromagnetic fields occupations and amyotrophic lateral sclerosis: a meta-analysis. *PLoS One* 7(11): e48354. DOI:10.1371/journal.pone.0048354.

# Appendix A: Common concerns about the New Zealand Standard for RF field exposure

This appendix addresses concerns that are sometimes expressed about NZS 2772.1:1999 *Radiofrequency Fields Part 1: Maximum exposure levels – 3 kHz to 300 GHz*.

## **‘The standard is out of date’**

Although at the time of this report’s publication the standard is 19 years old, in 2009 (following a review of more recent research, as discussed in Section 2.1) ICNIRP reaffirmed the limits on which it is based, and did so again in 2017. Reviews of the health research carried out since 1999 by national and international expert panels have also found no good reason to revise the fundamental limits.

On the other hand, ICNIRP and others note recent dosimetry data suggesting that under certain circumstances (particular combinations of frequency, body size, posture and radio signal polarisation), exposure at the reference levels might result in the basic restrictions being exceeded. However, it seems unlikely that such an event would have any health effects because of the large safety factors used to derive the basic restrictions.

## **‘The standard only considers thermal effects’**

The ICNIRP limits used in the standard are based on a review of all relevant research on health effects, regardless of the mechanism that might be involved. ICNIRP and other expert panels that have reviewed the data find that the only effects that show up with any clarity are consistent with the effects of heat stress, and occur at exposure levels at which absorption of RF energy in the body (as heat) exceeds the body’s ability to dissipate that heat. Exposures below the ICNIRP limits would prevent these effects.

Most of the research conducted over the past 30 years has used exposures that are at or below the ICNIRP limits, but no consistently reproducible or persuasive evidence of health effects, from any cause, has been found.

In summary, the standard takes into account the possibility of health effects from any cause, but thermal effects are the only ones for which research has found clear evidence.

## **‘The standard does not consider long-term effects’**

Limits in the standard are based on an evaluation of data from a range of sources. The sources include laboratory studies on cell cultures, animals or people exposed to RF fields under well-defined conditions, and observational (epidemiological) studies that compare the health of different groups of people who, because of their activities or where they live or work, may have different exposures.

Information on the effects of long-term exposures comes from both epidemiological studies and laboratory studies on animals that are exposed for large parts (or all) of their lifetimes. (Some studies have even exposed laboratory animals over several generations.) These findings are all taken into account in determining what health effects are produced by exposures to RF fields, and the levels at which they occur.

## **‘The standard of proof ICNIRP applies is too high’**

ICNIRP (as well as other expert panels) applies quality criteria to studies used in its evaluations that are similar to those that would be used in a health risk assessment for any other agent. It summarises its approach in a 2002 statement ‘General approach to protection against non-ionising radiation (ICNIRP 2002). Individual studies are assessed against criteria that allow the strength of the findings to be evaluated (eg, Were laboratory studies double-blinded to safeguard against conscious or unconscious bias in their evaluation? Was the exposure properly evaluated and checked? Were appropriate statistical techniques used when analysing the data?).

As new research and new findings accumulate, they are assessed in the context of existing data, and an overall evaluation is made based on all the relevant data, not just the new material. Where the data is ambiguous or uncertain, informed judgements are made following schemes such as the Hill criteria (Hill 1965).

# Appendix B: The IARC classification scheme

Group	Meaning (number of agents)	Basis for classification		Everyday examples
		Evidence from human studies	Evidence from animal studies	
1	Carcinogenic (120 agents as at June 2018)	Positive associations: chance, bias and confounding can be ruled out.		X-rays Diesel engine exhaust Alcoholic beverages Ultra-violet (UV) radiation UV tanning devices Processed meat
2A	Probably carcinogenic (82 as at June 2018)	Positive associations for which a causal interpretation is credible, but could also be due to chance, bias or confounding.	Causal relationship established in 2 or more species, or 2 or more independent studies in a single species.	PCBs Fumes from hot frying Red meat
2B	Possibly carcinogenic (302 as at June 2018)	<b>Either:</b> positive associations for which a causal interpretation is credible, but could also be due to chance, bias or confounding or has weaknesses that mean no conclusions can be drawn  <b>or:</b> evidence has weaknesses that mean no conclusions can be drawn.	The data suggests a carcinogenic effect but is too limited to make a definitive evaluation.  Causal relationship established in 2 or more species, or 2 or more independent studies in a single species.	Pickled vegetables (traditional in Asia) Petrol engine exhaust ELF magnetic fields RF fields
3	Not classifiable (501 as at June 2018)	Have weaknesses that mean no conclusions can be drawn.	<b>Either</b> the data suggests a carcinogenic effect but is too limited to make a definitive evaluation, <b>or</b> the data has major quantitative or qualitative limitations.	Chlorinated drinking water Coffee Tea Static electric and magnetic fields ELF electric fields
4	Probably not carcinogenic (1 as at June 2018)	Several studies, covering the range of human exposures, which consistently show no increased risk. Bias and confounding can be ruled out, and there is an adequate follow-up time.		Caprolactam (chemical used in the production of Nylon-6, which is widely used in fibres and plastics)

\* This table summarises the minimum requirements that must be satisfied in most cases, but there may be exceptions. For a full overview of the IARC process and classification scheme, refer to <http://monographs.iarc.fr/ENG/Preamble/CurrentPreamble.pdf>

# Appendix C: Recent ELF reviews

Date	Group and publication date	Mandate, area covered and method	Conclusions
May 2018	SSM (Swedish Radiation Safety Authority) Scientific Council on Electromagnetic Fields (2018, May)	See description for SSM (2014, March) review below.	<p>In cellular studies, the most frequent end point for which effects were reported related to oxidative stress. Some studies reported that exposure to ELF fields reduced the damage caused by subsequent application of a chemical or physical treatment.</p> <p>Some behavioural and cognitive disturbances were reported in animals exposed to fields around 1 mT. An exposure to 0.5 mT prevented effects linked to Alzheimer's disease in a mouse model. Studies using lower fields reported a variety of effects with no clear pattern.</p> <p>Epidemiology studies do not change the conclusions on childhood leukaemia.</p>
April 2018	Health Council of the Netherlands (2018, April)	<p>An update of earlier Health Council of the Netherlands reports in ELF fields, to be published in three parts. This first part covers childhood cancer.</p> <p>The report re-analyses data from previous studies, and considers childhood cancer risks in relation to measured exposures and distance from power lines.</p> <p>At present only the summary is available in English.</p>	<p>Leukaemia risk in children with an average exposure &gt;0.3–0.4 <math>\mu</math>T is about 2.5 times greater than in children exposed at 'background' level. There is considerable uncertainty in this estimate but it seems unlikely that there is no increased risk.</p> <p>For other types of cancer, only the data on brain tumours is sufficient for an analysis. There is no relationship with distance from power lines, but the risk is 1.5 times greater in children with average exposures &gt;0.4 <math>\mu</math>T. There is considerable uncertainty in this estimate and it could be due to chance.</p> <p>Overall the data is 'suggestive of a causal relationship' but does not indicate a 'likely' or 'proven' causal relationship because there is no supporting evidence from animal studies.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
July 2016	Biological Effects Policy Advisory Group on low-level EMFs, Institution of Engineering and Technology (2016, July)	Updates 2014 report from the same group. Assessment was based on peer-reviewed literature retrieved by monthly searches of INSPEC, MEDLINE and BIOSIS databases. Review also covers RF fields.	<p>The balance of evidence 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 due to such fields.</p> <p>Pooled analyses of epidemiological studies have shown an association between childhood leukaemia and higher levels of fields. However, in the absence of convincing mechanistic and experimental support, these findings do not provide good grounds to conclude that there is a causal relationship. A major epidemiological study published in 2014 suggests that the risk of childhood leukaemia associated with living near high-voltage power lines has decreased over the past 40 years and is no longer elevated. A subsequent Danish study has reported a similar decrease over time.</p> <p>The majority of cellular studies report effects, but the whole area is contradictory because opposing results can be found with apparently similar exposures and cells. A serious problem is that very few independent replication studies have been undertaken.</p>
May 2016	SSM Scientific Council on Electromagnetic Fields (2016, May)	See description for SSM (2014, March) review below. This review also gives an overview of how the research evidence has changed over the 13 years that SSM has produced these reports.	<p>Cellular studies provide inconsistent results, but one study reporting DNA damage following one day of exposure to 3 mT fields merits attempts to replicate. As in previous years, hypothesis- and mechanism-driven animal studies were rare, and results generally inconsistent. Two human studies suggest that very strong ELF magnetic fields may modulate cortical brain activity.</p> <p>New studies do not change current thinking on the ELF field-childhood leukaemia question. In contrast to the 2015 conclusions, a large Swedish study suggested that magnetic fields are not associated with ALS.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
February 2016	ARIMMORA (EU-funded programme, Advanced Research on Interaction Mechanisms of electroMagnetic exposures with Organisms for Risk Assessment) (Schuz et al 2016)	The project was set up to scrutinise the underlying biophysical mechanisms and to clarify a possible causal relationship between ELF field exposure and cancer, especially childhood leukaemia. The programme culminated in a risk assessment using findings from the research programme and other recent research, following the IARC methodology.	ARIMMORA used a transgenic mouse model to mimic the most common childhood leukaemia. New pathogenic mechanisms were indicated, but no definitive conclusions could be drawn. Overall there is limited evidence of carcinogenicity in humans and inadequate evidence of carcinogenicity in experimental animals, with only weak supporting evidence from mechanistic studies. The relationship between ELF fields and childhood leukaemia remains consistent with possible carcinogenicity in humans (IARC Class 2B). New exposure data from ARIMMORA confirmed that if the association is causal, up to 2% of childhood leukaemias in Europe (as previously estimated) may be attributable to ELF fields.
March 2015	SSM Scientific Council on Electromagnetic Fields (2015, March)	See description for SSM (2014, March) review below.	<p>In vitro studies have investigated a large variety of effects and exposure conditions, but few aim to address the association between exposure and childhood leukaemia. Animal studies have generally used high exposures. Many were poorly executed and described, and results are inconsistent. There were no informative human studies.</p> <p>While a UK study found a notable decrease over time in the association between childhood leukaemia and distance from power lines, this is hard to explain. If there is another risk factor involved, it must be very strong to have such an effect.</p> <p>Studies on adult cancers frequently provided inconsistent results, and findings do not change existing conclusions.</p> <p>Recent studies suggest that an association between ELF magnetic field exposure and ALS or Alzheimer's disease may exist, and justify further research.</p>
March 2015	SCENIHR (EU Scientific Committee on Emerging and Newly Identified Health Risks) (2015, March)	<p>Updates previous reports by the same group in 2007 and 2009. Assessment was based on articles in peer-reviewed journals, applying SCENIHR criteria for weight of evidence approach for risk assessment (SCENIHR 2012).</p> <p>Draft assessment released in 2014 for public consultation, before preparing final report.</p> <p>Review also covers RF fields.</p>	<p>No convincing evidence of a link between ELF exposures and self-reported symptoms.</p> <p>New epidemiology studies consistent with previous findings of an increased risk of childhood leukaemia. However, there is no experimental support for a link and no mechanism identified, which prevents a causal interpretation.</p> <p>Epidemiological studies provide no convincing evidence of an increased risk of neurodegenerative diseases, and no evidence for adverse pregnancy outcomes.</p> <p>Recent results show no effect on human reproductive functions.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
March 2014	SSM Scientific Council on Electromagnetic Fields (2014, March)	<p>Updates previous (usually annual) reports from the same group.</p> <p>Assessment was based on articles in peer-reviewed journals. Articles are assessed to determine the weight they should be given in overall assessment; evidence from different types of research (eg, epidemiology, in vivo and in vitro studies) is integrated in final stage of evaluation. Epidemiology data is given greatest weight. Studies considered to have insufficient scientific quality are not included.</p> <p>Aim is to determine whether a hazard exists: the answer may not be a clear yes or no but express the likelihood that there is a hazard. If there is a hazard, the assessment should evaluate the exposure–response function.</p> <p>Review also covers RF fields.</p>	<p>A consistent association has been observed between exposure to ELF magnetic fields and childhood leukaemia, but a causal relationship has not been established.</p> <p>A large French study found some indications for an increased childhood leukaemia risk. A large pooled study found no evidence that survival of childhood leukaemia patients was affected by ELF field exposure, but the results may be affected by exposure misclassification.</p> <p>Absence of risk was confirmed in most studies of adult cancers.</p> <p>Any relationship with Alzheimer’s disease and ALS is still unresolved.</p> <p>In vitro studies have investigated a large variety of effects, but few address the childhood leukaemia question. Several studies lack sham-exposed controls.<sup>23</sup></p> <p>The results of in vivo studies are not very consistent and need replication. These should address the childhood leukaemia question.</p> <p>ELF magnetic fields do not seem to have any effects on general physiology. Effects on the EEG have been observed, but it is difficult to distinguish between statistically significant and physiologically meaningful effects.</p>
May 2014	Biological Effects Policy Advisory Group of the Institution of Engineering and Technology (2014, May)	<p>Updates 2012 report from the same group.</p> <p>Assessment was based on peer-reviewed literature retrieved by monthly searches of INSPEC, MEDLINE and BIOSIS databases.</p> <p>Review also covers RF fields.</p>	<p>On the balance of evidence from the last few decades, harmful health effects from environmental levels remain unsubstantiated.</p> <p>There is no generally accepted experimental demonstration of any biological effect from environmental levels.</p> <p>Pooled analyses of epidemiological studies show an association between childhood leukaemia and high field levels, but the lack of mechanistic or experimental evidence does not support the existence of a causal relationship. A major epidemiological study published in 2014 suggested that the incidence of leukaemia in children living near power lines has decreased over the past 40 years and is no longer elevated.</p> <p>The high proportion of EMF studies that report effects but a subsequent inability to replicate them suggests that better -quality control should be applied before publication.</p>

<sup>23</sup> A sham-exposed control is an experimental animal or cell culture that has been handled in exactly the same way as the animals or cultures exposed to the agent under investigation, but has not received any exposure.

Date	Group and publication date	Mandate, area covered and method	Conclusions
March 2013	SSM Scientific Council on Electromagnetic Fields (2013, March)	<p>Updates previous (usually annual) reports from the same group.</p> <p>Assessment was based on articles in peer-reviewed journals. Articles assessed to determine the weight they should be given in overall assessment; evidence from different types of research (eg, epidemiology, in vivo and in vitro studies) is integrated in the final stage of evaluation. Epidemiological data is given greatest weight. Studies considered to have insufficient scientific quality are not included.</p> <p>Aim is to determine whether a hazard exists: the answer may not be a clear yes or no but express the likelihood that there is a hazard. If there is a hazard, the assessment should evaluate the exposure–response function.</p> <p>Review also covers RF fields.</p>	<p>The question of whether ELF magnetic fields have any influence on the development of childhood leukaemia is still unresolved.</p> <p>A large number of other health end points have been studied, but mostly without finding consistent associations.</p> <p>Recent environmental and occupational studies on Alzheimer’s disease have reported associations but a causal relationship is not established.</p>
October 2012	European Health Risk Assessment Network on Electromagnetic Fields (EFHRAN 2012, October)	<p>Project funded by the European Commission. The Network includes participants from universities and research centres in seven European countries, and collaborating partners from eight other countries or organisations, including WHO.</p> <p>Builds on previous European-funded collaborations investigating and collating results of EMF research.</p> <p>Evaluated strength of evidence using a system similar to IARC.</p> <p>Review also covers RF fields.</p>	<p>Limited evidence (ie, evidence restricted to a few studies, or unanswered questions about the design, conduct or interpretation of the studies, or confounding factors cannot be ruled out with confidence) was found of an association between ELF magnetic fields and leukaemia in children. A combination of chance, bias and confounding may have produced this result.</p> <p>Inadequate evidence (ie, studies of insufficient quality, consistency or statistical power to draw conclusions) was found for Alzheimer’s disease, ALS and brain tumours in children. However, the data suggests that some risks may exist, particularly for Alzheimer’s disease, so further studies would be useful. Evidence is also inadequate for all other cancers (except breast cancer), other neurodegenerative diseases, and non-specific symptoms, but it does not appear worthwhile to conduct further studies.</p> <p>The evidence suggests a lack of effects (ie, no effects found in several independent studies, under different protocols involving at least two species or cell types and a range of exposures) for breast cancer in adults, cardiovascular diseases and EHS.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
May 2012	Biological Effects Policy Advisory Group of the Institution of Engineering and Technology (2012, May)	Updates previous reports from the same group. Assessment was based on peer-reviewed literature retrieved by monthly searches of INSPEC, MEDLINE and BIOSIS databases. Review also covers RF fields.	<p>The balance of evidence suggests that the existence of harmful effects has not been substantiated but this remains a possibility. No generally accepted demonstration of a biological effect has been established.</p> <p>Pooled analyses of epidemiological studies show an association with childhood leukaemia, but in the absence of mechanistic and experimental evidence these findings do not provide good grounds to conclude that a causal relationship exists. Selection bias and confounding remain possible explanations for the results.</p>

# Appendix D: Recent RF reviews

Date	Group and publication date	Mandate, area covered and method	Conclusions
May 2018	SSM (Swedish Radiation Safety Authority) Scientific Council on Electromagnetic Fields (2018, May)	See description for SSM (2014, March) review below.	<p>A variety of animal studies was reported, with varying end points and inconsistent results. Some studies reported increased oxidative stress at low exposures, but the levels decreased after longer exposures.</p> <p>New results on the human waking EEG are inconsistent. No effects were found on cognitive performance or symptoms.</p> <p>Cancer registry studies mainly point towards no association between mobile phone use and brain tumours. Studies on mobile phones and sperm quality had limitations and are uninformative.</p> <p>The report notes again that many studies were excluded from consideration due to poor quality and missing information. These, along with the reasons for not being considered, are listed in an appendix.</p>
March 2018	Expert working group set up by the French Agency for Food, Environmental and Occupational Health & Safety (ANSES 2018, March)	<p>Objectives were to:</p> <ul style="list-style-type: none"> <li>• attempt to understand complexities of EHS and characterise it</li> <li>• examine the plausibility of various assumptions made to explain the causes of the reported disorders.</li> </ul> <p>Also looks at ELF fields as a potential cause.</p> <p>Appraisal by expert group based on literature search, supplemented by additional references solicited from various sources and proposed during public consultation on draft report. Conducted according to French standard for expert appraisals.</p>	<p>The most common symptoms described are fatigue and sleep disorders, but there are many others as well. The symptoms have been attributed by individuals to a variety of ELF and RF sources. The pain and suffering described by EHS individuals are a reality. Research into clinical, biological and physiological bases has not found any diagnostic criteria, and the only way available now to define EHS is on the basis of self-reporting.</p> <p>No studies show that people can perceive RF fields, and provocation studies do not show that symptoms develop during or after exposure. Data investigating other possible causes is generally sparse and patchy.</p> <p>The expert group recommended a wide range of further research.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
July 2016	Biological Effects Policy Advisory Group (2016, July), Institution of Engineering and Technology	Updates 2014 report from the same group. Assessment was based on peer-reviewed literature retrieved by monthly searches of INSPEC, MEDLINE and BIOSIS databases. Review also covers ELF fields.	<p>The existing data does not provide persuasive evidence that harmful health effects exist. Recent analyses of historical brain tumour rates suggest that the high risks reported in some studies of mobile phone use are implausible. Overall, the epidemiological evidence over the past two years, coupled with that from previous studies, and the absence of clear evidence of health effects, could be regarded as reassuring.</p> <p>In contrast to previous review periods, the number of animal studies showing no effects was about the same as the number showing effects for both central nervous system exposures and in studies on reproduction and development. Oxidative stress has been examined in many studies and effects have consistently been reported in various tissues, including brain and liver.</p> <p>There is considerable doubt about the claimed cellular effects at field levels to which the public might be exposed. Relatively few replication studies have been undertaken and most do not confirm the claimed effects. Furthermore, the effects claimed do not follow a consistent pattern in terms of exposure parameters or biological response.</p>
June 2016	Health Council of the Netherlands (2016, June) Electromagnetic Fields Committee	<p>Represents the third of three reports investigating whether exposures from mobile phones could cause cancer (the first report, covering epidemiology, was published in 2013 and the second, covering animal studies, was published in 2014).</p> <p>This report updates the two previous reports following the same methodology (systematic search, quality evaluation and analysis of the relevant literature), and draws conclusions from all the research considered using the Bradford Hill criteria.</p>	<p>There is no proven association between long-term and frequent use of a mobile phone and an increase in the risk of tumours in the brain, head and neck. Based on the strength of the evidence, it can only be concluded that such an association cannot be ruled out. The Committee considers it unlikely that exposure to radiofrequency fields from the use of mobile phones causes cancer. The animal data indicates the possibility of a promoting effect, but it is not clear whether this could explain the increased risk of tumours that has been observed in some epidemiological studies. The Committee feels it more likely that a combination of bias, confounding and chance might be an explanation for the epidemiological observations.</p> <p>Therefore the value of any measures to reduce exposures is unclear, but the Committee suggests again that exposures should be as low as reasonably achievable.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
June 2016	Expert working group set up by the French Agency for Food, Environmental and Occupational Health & Safety ANSES (2016, June)	<p>Objectives included to:</p> <ul style="list-style-type: none"> <li>• produce an inventory of radio products intended for under six-year-olds and assess the exposures from them</li> <li>• review current regulations covering RF exposures of children</li> <li>• analyse the research on RF and health, especially related to children's health</li> <li>• assess potential health risks to children from RF exposures from devices intended for them.</li> </ul> <p>Methodology was the same as that adopted in the ANSES (2013) review of health effects of RF fields – see below.</p>	<p>There are now many devices used by young children. Tests showed that the SAR in 'body-worn' positions often exceeded 2 W/kg if the recommended separation distance was not respected (which probably often occurs in reality). (This applies to children and adults.) At some frequencies, exposures at the reference levels could lead to exposures exceeding the basic restrictions.</p> <p>There are possible effects on cognitive functions and wellbeing, but for the latter this may be linked to phone use rather than RF fields from them. The current data does not permit conclusions to be drawn about effects on behaviour, hearing, development, reproductive systems, cancer, the immune system or toxicity.</p> <p>The working group recommended that SAR testing be made in actual conditions of use, and that these results should be included in product literature. Existing regulations controlling advertising mobile phones to children should be extended to other RF devices. Use of radio devices by children should be limited, especially at night time.</p> <p>For the cancer end points, the working group concluded that there was inadequate evidence except for a 'possible' effect on gliomas for heavy users, and a 'limited' level of proof for acoustic neuromas. Short-term effects have been observed on sleep EEG, but this seems to have no harmful effects.</p> <p>Users should be provided with information on SAR from devices, along with the means to reduce exposure, should they wish to do so.</p> <p>In addition to the recommendations from the working group, ANSES recommended:</p> <ul style="list-style-type: none"> <li>• encouraging children to moderate their mobile phone use, and that heavy users and children should use hands-free kits and phones with a low maximum SAR</li> <li>• making no changes to existing French exposure limits.</li> </ul>

Date	Group and publication date	Mandate, area covered and method	Conclusions
May 2016	SSM Scientific Council on Electromagnetic Fields (2016, May)	See description for SSM (2014, March) review below. This review also gives an overview of how the research evidence has changed over the 13 years that SSM has produced these reports.	<p>In vitro studies have again investigated several end points and usually found no effects. Animal studies again show inconsistent signs of oxidative stress, sometimes at very low exposures. One animal study found DNA damage at low exposures, but should be replicated, and another that found increased cancer risk showed no dose-response characteristics and the animal used was unlikely to predict effects in humans.</p> <p>An EEG study found some effects, but not entirely consistent with previous studies. Generally no effects have been found on cognitive performance, nor have effects on mood, wellbeing, somatic complaints, subjective sleep quality and physiological parameters.</p> <p>A large Norwegian study found that maternal mobile phone use during pregnancy did not pose reproductive health risks, but in future better dosimetry is needed. Further associations between mobile phone use by children and adolescents have been reported, but suggest that factors other than RF fields (eg, sleep deprivation, lack of recreation) may be the explanation.</p> <p>As noted in previous years, several published studies conveyed no useful information, often because of poor dosimetry or no sham-exposed control group.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
March 2015	SSM Scientific Council on Electromagnetic Fields (2015, March)	See description for SSM (2014, March) review below.	<p>Most in vitro studies do not show effects of RF exposure, but some report indications of oxidative stress. Suggestions of an adaptive response have been replicated, but further work is needed to draw firm conclusions.</p> <p>Many animal studies were not useful because of poor dosimetry or design. There are inconsistent indications of oxidative stress and effects on testes and sperm, and mixed results on learning and behaviour.</p> <p>One human study found no effect of RF exposure on EEG during sleep, and no effects on heart rate variability were found. Recent epidemiology studies are consistent with previous work in demonstrating an association between heavy mobile phone use and brain tumours, but may also be affected by recall bias. A large Swiss study found no association between childhood cancer and exposure to broadcasting RF fields, consistent with two previous case-control studies. Recent studies on sperm quality cannot be evaluated due to the poor quality of the research. Cross-sectional studies on adolescent mobile phone use and occurrence of symptoms find associations, but these could be due to RF fields, the fact of using mobile devices or other confounders (eg, personality type).</p>
March 2015	SCENIHR (EU Scientific Committee on Emerging and Newly Identified Health Risks) (2015, March)	<p>Updates previous reports by the same group in 2007 and 2009. Assessment was based on articles in peer-reviewed journals, applying SCENIHR criteria for weight of evidence approach for risk assessment (SCENIHR 2012).</p> <p>Draft assessment released in 2014 for public consultation before preparing final report.</p> <p>Review also covers ELF fields.</p>	<p>Overall, epidemiology studies show no increased risk of brain tumours or other cancers of the head and neck, although the possibility of an association with acoustic neuroma remains. Epidemiology does not suggest an increased risk of other malignant diseases, including childhood cancer.</p> <p>Recent studies support the possibility of an effect on the EEG. Pulse-modulated signals may affect different parts of sleep and different EEG frequencies. However, given the variety of exposure conditions used, no firm conclusions can be drawn.</p> <p>Research since the 2009 SCENIHR review supports the conclusion that RF field exposures do not cause the physical symptoms that some people attribute to them.</p> <p>Recent research does not suggest any effects on reproduction and development from exposures that comply with current limits. Human studies on child development and behaviour have had conflicting results and methodological limitations.</p> <p>Studies on male infertility are poor and provide little evidence.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
September 2014	Health Council of the Netherlands (2014, September) Electromagnetic Fields Committee	<p>Represents the second of three reports investigating whether exposures from mobile phones could cause cancer (the first report, covering epidemiology, was published in 2013).</p> <p>This report is a systematic review of animal studies investigating the potential carcinogenicity of RF fields.</p> <p>Assessment was based on peer-reviewed literature retrieved by searches of PubMed, EMF Portal and Web of Science databases.</p> <p>Quality of studies was assessed using criteria based on the Gold Standard Publication Checklist.</p>	<p>On the basis of the results, it is unlikely that long-term continuous or repeated exposure to RF fields may initiate or promote the development of cancer.</p> <p>While a few studies did indicate effects, the findings have either not been observed in repetition studies or might be explained by thermal effects. The same comments apply to studies that suggested protective effects.</p> <p>Further research in this area should await the findings of a large study currently in progress in the USA.</p>
May 2014	Biological Effects Policy Advisory Group of the Institution of Engineering and Technology (2014, May)	<p>Updates 2012 report from the same group.</p> <p>Assessment was based on peer-reviewed literature retrieved by monthly searches of INSPEC, MEDLINE and BIOSIS databases.</p> <p>Review also covers ELF fields.</p>	<p>Existing data does not provide persuasive evidence of harmful effects.</p> <p>Recent analyses of historical brain tumour rates show no increases corresponding to the rapid expansion of mobile phone use. Although the length of time before such effects would be evident is uncertain, this finding demonstrates that some of the more extreme epidemiological findings are implausible.</p> <p>Experimental studies have not shown consistent effects, and have not found a mechanism through which low-level RF fields could produce effects.</p> <p>An increasing proportion of mobile phone studies (currently 75%) report effects, which suggests that such effects are common and should be readily demonstrated. However, in practice this is not the case. The assumption that peer-reviewed published studies are robust and replicable does not appear to hold and is increasingly being challenged in other areas. UK research programmes were unable to replicate key EMF studies.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
April 2014	Royal Society of Canada expert panel (Demers et al 2014, April)	<p>Panel appointed by Royal Society of Canada to review Health Canada's proposed RF exposure limits (Safety Code 6 – SC6). Specific focus on the emerging evidence on potential health risks of RF from wireless telecommunication devices, as well as from other sources in range 3 kHz–300 GHz. The panel should determine whether: the proposed code provides adequate protection, whether other potential health effects should be considered and whether additional precautionary measures should be recommended.</p> <p>Based mainly on recent reviews by expert groups, but also looked at relevant papers published since those reviews.</p> <p>Consideration of recent dosimetry, several specific health outcomes (eg, cancer, EHS, cognitive effects, reproductive effects, development), and thermal/non-thermal effects.</p>	<p>Basic restrictions are adequate for protection against heating effects. At some frequencies, exposures at reference levels might result in basic restrictions being exceeded, but it is very unlikely this will have adverse effects.</p> <p>The balance of evidence does not indicate that exposures that comply with SC6 cause adverse health effects.</p> <p>The evidence that exposure below the limits causes cancer is weak.</p> <p>There is no firm evidence that RF exposures cause EHS, but the condition should be investigated further to try to understand the aetiology and possible treatments.</p> <p>If exposures comply with the limits, no health effects have been established (ie, health effects observed consistently in several studies with strong methodology) related to cognitive and neurological systems, reproduction, development, cardiac function, heart rate variability, or the eye.</p> <p>No additional precautionary measures should be incorporated into the SC6 limits. However, more information should be made available on RF exposures and the devices that produce them, and how people can reduce exposures if they wish.</p> <p>Further research is needed to clarify the question of an RF–cancer link, and other possible effects at exposures that comply with the SC6 limits.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
March 2014	ARPANSA Radiofrequency Expert Panel (2014, March)	<p>Panel composed of three Australian academics with expertise in biophysics, human provocation and epidemiology, and three ARPANSA scientific staff.</p> <p>Panel was requested to:</p> <ul style="list-style-type: none"> <li>• review research since 2000 to assess whether there have been significant changes to the science, and whether the findings would affect the guidance provided by RPS3 (ARPANSA RF exposure standard)</li> <li>• recommend whether a formal review of RPS3 should be undertaken</li> <li>• prepare an independent assessment of the RF research literature for publication.</li> </ul> <p>Based on major reviews and review papers published between 2000 and 2012, an ARPANSA literature search covering the period 2000 to August 2012, and an ARPANSA review of epidemiological and human provocation research.</p>	<p>In vitro and in vivo studies give indications of some effects, but these often appear to occur at levels higher than typical exposures or relate to subtle biological effects not necessarily related to disease, and that to date are not apparently replicable. Most discipline-based reviews conclude that thermal effects are adequate to explain the data, supporting the use of basic restrictions based on thermal effects. However, the variability of the science supports the rationale for a precautionary approach.</p> <p>Human provocation studies have investigated a range of possible effects (eg, cognitive effects, cardiovascular effects, subjective symptoms). The results support the adequacy of the RPS3 limits.</p> <p>Recent dosimetry research has confirmed the conservatism of current exposure limits under most circumstances. However, the current reference levels may not guarantee meeting basic restrictions for all body sizes in some frequency ranges (so the safety margins provided by reference levels may be lower than intended). The localised SAR in limbs under resonant conditions may produce higher temperature rises than previously thought, and the acceptability of this should be reviewed.</p> <p>Epidemiology studies have not progressed with any dose–response relationships that would warrant significant changes to RPS3.</p> <p>Overall, the Expert Panel found that the underlying basis of the ARPANSA RF exposure standard remains sound and that the exposure limits in the standard continue to provide a high degree of protection against the known health effects of RF electromagnetic fields. While the findings of the Expert Panel in this report give confidence that the 2002 standard provides adequate protection, they identify areas where RPS3 and its annexes could be updated to take account of increased knowledge and to better harmonise with international standards.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
March 2014	SSM Scientific Council on Electromagnetic Fields (2014, March)	<p>Updates previous (usually annual) reports from the same group.</p> <p>Assessment was based on articles in peer-reviewed journals. Articles assessed to determine the weight they should be given in overall assessment; evidence from different types of research (eg, epidemiology, in vivo and in vitro studies) is integrated in the final stage of the evaluation. Epidemiology data is given greatest weight. Studies considered to have insufficient scientific quality are not included.</p> <p>Aim is to determine whether a hazard exists: the answer may not be a clear yes or no but express the likelihood that there is a hazard. If there is a hazard, the assessment should evaluate the exposure–response function.</p> <p>Review also covers ELF fields.</p>	<p>Most in vitro studies do not support an effect of RF on DNA damage or cell death, only minimal effects on protein expression.</p> <p>Overall, in vivo studies provide weak indications of possible effects on oxidative stress and brain function, including behaviour and emotionality. Reported effects on genotoxicity, hormones, glucose, male fertility and reproduction mostly come from single studies and need well-designed replication. The majority of recent studies have no clear hypothesis and poor study design, and the dosimetry is poorly described.</p> <p>Two studies showed no effect on cognitive functions, while a third found that exposure improved performance. Effects on EEG may depend on age and any central nervous system pathologies (eg, epilepsy). Sleep studies find EEG effects at various frequency bands and stages of sleep. No effects on physiological parameters were observed.</p> <p>A new study by the Hardell group reported an increased risk of glioma with clear dose–response trends, but there is a discrepancy between these results and time trends in glioma incidence. A Swedish study found no increase in salivary gland tumours between 1979 and 2009. Many studies on non-cancer outcomes have limitations and no firm conclusions can be drawn.</p> <p>Experimental studies find no effects of acute RF exposure on EHS. Recent findings on the interaction between risk perception and EHS may be helpful for risk management.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
October 2013	Expert working group set up by the French Agency for Food, Environmental and Occupational Health & Safety (ANSES 2013, October)	<p>Updates 2009 opinion.</p> <p>Concentrates on effects potentially related to wavelengths used by new or developing technologies.</p> <p>Evaluates all potential health effects (except 'electro hypersensitivity', to be dealt with separately), based on a literature search covering the period since the previous appraisal.</p> <p>Quality of studies assessed; terminology of evaluation similar to IARC. Concentrates on studies in which exposure conditions could not cause overall temperature increase.</p>	<p>The working group concluded that for all the non-cancer health effects studied, there was 'inadequate' evidence<sup>24</sup> to conclude there is a real effect on human health.</p> <p>For the cancer end points, the working group concluded that there was inadequate evidence, except for a 'possible' effect on gliomas for heavy users, and a 'limited' level of proof for acoustic neuromas.</p> <p>Short-term effects have been observed on sleep EEG, but this seems to have no harmful effects.</p> <p>Users should be provided with information on SAR from devices, along with the means to reduce exposure, should they wish to do so.</p> <p>In addition to the recommendations from the working group, ANSES recommended:</p> <ul style="list-style-type: none"> <li>• encouraging children to moderate their mobile phone use, and that heavy users and children should use hands-free kits and phones with a low maximum SAR</li> <li>• making no changes to existing French exposure limits.</li> </ul>

<sup>24</sup> A conclusion of 'inadequate' evidence overall is based mainly on the inadequacy of evidence from human studies. According to the report, this means that the human evidence:

- showed no effect, or
- was of insufficient quality or consistency, or was not statistically powerful enough, to determine whether a cause-and-effect relationship exists or not, or
- does not exist.

Date	Group and publication date	Mandate, area covered and method	Conclusions
March 2013	SSM Scientific Council on Electromagnetic Fields (2013, March)	<p>Updates previous (usually annual) reports from the same group.</p> <p>Assessment was based on articles in peer-reviewed journals. Articles assessed to determine the weight they should be given in the overall assessment; evidence from different types of research (eg, epidemiology, in vivo and in vitro studies) is integrated in the final stage of the evaluation. Epidemiology data is given the greatest weight. Studies considered to have insufficient scientific quality are not included.</p> <p>Aim is to determine whether a hazard exists: the answer may not be a clear yes or no but express the likelihood that there is a hazard. If there is a hazard, the assessment should evaluate the exposure–response function.</p> <p>Review also covers ELF fields.</p>	<p>Evidence from epidemiological studies on mobile phone use and brain tumour risk, together with national cancer incidence statistics from various countries, is not convincing in linking mobile phone use to tumours of the head in adults. There is scientific uncertainty for regular use longer than 13–15 years.</p> <p>It is too early to draw firm conclusions for children and adolescents regarding mobile phone use and brain tumour risk, but the literature to date does not indicate an increased risk.</p> <p>The most consistently observed biological effect from mobile phone exposure is an increase in power in part of the EEG spectrum in volunteer studies. The effect is weak and is unrelated to behavioural or health effects, and there is a large variation between individuals. The mechanism is unknown.</p> <p>Recent research does not indicate public health risks related to RF exposures from cell sites, broadcast transmitters or WiFi in homes or schools.</p> <p>Symptoms experienced by people with perceived EHS are real, and sometimes severe, but studies have not shown that they are caused by EMFs. Several studies have indicated a nocebo effect.</p>
June 2013	Health Council of the Netherlands (2012, June) Electromagnetic Fields Committee	<p>Represents the first of three reports investigating whether exposures from mobile phones could cause cancer.</p> <p>Assessment was based on peer-reviewed literature retrieved through searches, quality evaluation and systematic review.</p>	<p>There are some weak and inconsistent indications for an association between prolonged and intensive use of a mobile phone and increased incidence of gliomas. This might be explained by bias and chance, but a causal relation cannot be excluded.</p> <p>For other types of tumour, indications of an increased risk are much weaker or are absent.</p> <p>Overall, there is no clear and consistent evidence of an increased risk associated with up to about 13 years of use of a mobile phone, but a risk cannot be excluded. No comment can be made about use over longer periods.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
October 2012	European Health Risk Assessment Network on Electromagnetic Fields (EFHRAN 2012, October)	<p>Project funded by the European Commission. The Network includes participants from universities and research centres in seven European countries, and collaborating partners from eight other countries and organisations, including WHO.</p> <p>Builds on previous European-funded collaborations investigating and collating the results of EMF research.</p> <p>Evaluated strength of evidence using system similar to IARC.</p> <p>Revision of a 2010 version of the report to include more recent studies of RF and brain tumours.</p> <p>Review also covers ELF fields.</p>	<p>Limited evidence (ie, evidence restricted to a few studies, or unanswered questions about the design conduct or interpretation of the studies, or confounding factors cannot be ruled out with confidence) was found for an association between RF fields and adult brain tumours. The classification is uncertain because it is based on two large studies with unresolved questions about possible biases and errors. The time trends are incompatible with large increases in brain tumours caused by mobile phone use.</p> <p>Inadequate evidence (ie, studies of insufficient quality, consistency or statistical power to draw conclusions) was found for neurodegenerative diseases, childhood cancers, other cancers, reproductive outcomes, cardiovascular diseases, or development of symptoms such as migraine and vertigo.</p> <p>Evidence suggesting lack of effects (ie, no effects found in several independent studies, under different protocols involving at least two species or cell types and a range of exposures) was found for EHS.</p>
September 2012	Expert committee appointed by the Norwegian Institute of Public Health (2012, September)	<p>Assessment was based on recent research reports and expert review group reports by international and national expert groups.</p> <p>Focused on research investigating possible health effects of weak fields (defined as fields below ICNIRP reference levels).</p>	<p>A large number of studies examining the possible effects of weak RF fields have been carried out and provide no evidence of adverse health effects. Some measurable biological or physiological effects cannot be ruled out.</p> <p>As exposures are typically well below the ICNIRP limits, there is no reason to assume they are associated with health risks. The uncertainty in this assessment is small.</p> <p>A large number of studies provide evidence that electromagnetic fields do not cause the symptoms experienced by people who consider themselves suffering from EHS. However, the problems are genuine and must be taken seriously.</p> <p>The expert committee does not recommend special measures to reduce exposure (eg, by changing limit values, currently based on ICNIRP levels). Administrative authorities can select the lowest-level precautionary strategy that 'any exposure should not be higher than for the intended purpose to be achieved'.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
June 2012	Swedish Council for Working Life and Social Research (2012, June)	<p>The Council was commissioned by the Swedish Government to monitor research into EHS and prepare reports on the state of research.</p> <p>Report covers the 10 years for which the mandate was active, and looks at the development of knowledge over that time.</p> <p>Also looks at epidemiological studies on RF and cancer risks.</p> <p>Focused on possible health risks related to RF exposures through mobile phone communication.</p>	<p>A considerable number of provocation studies on RF exposures and symptoms have been unable to show any association.</p> <p>Overall, the data on brain tumours and mobile telephony does not support an effect of mobile phone use on cancer risk, in particular when taken together with national cancer trend statistics throughout the world.</p> <p>Research on mobile telephony and health started without a biologically or epidemiologically based hypothesis about possible health risks. Extensive research for more than a decade has not detected anything new regarding interaction mechanisms between RF fields and the human body and has found no evidence for health risks below current exposure guidelines.</p>
May 2012	Biological Effects Policy Advisory Group of the Institution of Engineering and Technology (2012, May)	<p>Updates previous reports from the same group.</p> <p>Assessment was based on peer-reviewed literature retrieved by monthly searches of INSPEC, MEDLINE and BIOSIS databases.</p> <p>Review also covers ELF fields.</p>	<p>The data does not provide persuasive evidence that harmful effects exist.</p> <p>The Interphone study group concludes that its results do not show an increase in brain tumours that could be interpreted as causal, but possible effects of long-term heavy use of mobile phones require further investigation. Analyses of historical brain tumour rates have not observed increases commensurate with the rapid expansion of mobile phone use, although the length of time before effects would appear is unknown.</p> <p>Experimental studies have failed to demonstrate consistent effects, and no mechanism has been established whereby low-level exposures to RF fields could cause biological effects.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
April 2012	UK Health Protection Agency Advisory Group on Non-ionising Radiation (Health Protection Agency 2012, April)	<p>Updates 2003 review by the same group, and concentrates on research published since then.</p> <p>Reviews quality of data to determine the weight given to individual findings.</p> <p>Generally considers human laboratory studies and epidemiological studies in greater detail than animal and cellular experiments as they are of greatest direct relevance to human health.</p>	<p>In vitro experiments find no consistently replicable effects from exposures that do not produce detectable heating. There is no convincing evidence that RF fields cause genetic damage or increase the likelihood of malignancies.</p> <p>Animal experiments provide no evidence of health effects from exposures below international guidelines.</p> <p>Evidence suggests that RF field exposures below guidelines do not cause acute symptoms or cognitive effects, and cannot be detected.</p> <p>There is some evidence that RF fields might affect EEG and other markers of brain function, but these effects have not been consistent across studies. The size of the effects is small relative to normal physiological changes, and it is unclear whether they have any implications for health.</p> <p>The limited research on effects of long-term exposures on non-cancer outcomes provides no substantial evidence of effects on cardiovascular morbidity, reproductive function or mortality.</p> <p>Although some positive findings have been reported in a few studies, overall the evidence does not suggest that mobile phones cause brain tumours or any other types of cancer. However, the data is restricted to periods of less than 15 years since first exposure.</p>

# Appendix E: The BioInitiative Report

The BioInitiative Report was first published in 2007 and was partially updated in 2012, 2014 and 2017. It reviews both ELF and RF research with the stated intention 'to document the reasons why current public exposure standards for non-ionizing electromagnetic radiation are no longer good enough to protect public health', and recommends much stricter limits than any national or international health agencies or review groups have proposed.

Several health and scientific bodies have reviewed the BioInitiative Report and noted that it has a range of weaknesses which undermine its credibility (AFSSET 2009; COMAR 2009; EMF-NET 2007; Health Council of the Netherlands 2008). Among these weaknesses are that:

- the stated objective was to use the publications cited to support a particular point of view (rather than to systematically review publications, assess them for their strengths and weaknesses, and form conclusions after that review)
- the conclusions were not a consensus view of the chapter authors (some of whom disagreed with the conclusions)
- data was used selectively (eg, virtually no studies on long-term exposures of animals to RF fields were discussed), with little or no mention of reports that do not support the conclusions
- no rationale was presented for the very low RF exposure limits proposed.

The following are specific examples of weaknesses in the report.

**Section 6 on genetic effects** (supplement for the 2012 and 2014 versions) lists abstracts and counts up the numbers showing effects or no effects (65% and 35% respectively for RF fields). There is a brief uncritical discussion of the findings but no attempt to explain apparently contradictory results, or discussion of the strengths and weaknesses of the individual studies.

Before the listing of abstracts, this comment is made:

It must be pointed out that, consistent with previous research, not very much of the cellular and animal genetic research data directly indicate that EMF (both RF and ELF EMF) is a carcinogen.

While the bare statistics on papers showing effects and no effects are carried through to the summary section 24 of the BioInitiative Report, this comment is not.

**Section 12 on ELF fields and childhood leukaemia** (2012 update replaces the 2007 version) claims that 'Except ionizing radiation no other environmental factor has been as firmly established to increase the risk of childhood leukaemia', and uses this as an argument to have ELF fields classified as carcinogenic. In contradiction to this statement, a 2012 review of *Childhood Leukaemia and Environmental Factors* published

jointly by the Health Council of the Netherlands, the Superior Health Council Belgium and the European Science Advisory Network for Health found that benzene, paternal smoking and PCBs were 'likely' risk factors; pesticides were 'possible to likely'; and ELF fields were 'possible' risk factors, along with formaldehyde, arsenic in drinking water, maternal smoking, parental alcohol consumption and plasticisers. (In addition, early social contacts and breastfeeding were likely protective factors.)

The author of this section dismisses confounding as a possible explanation for the associations found between ELF fields and childhood leukaemia, on the grounds that the confounding agent must be quite strong and present wherever studies have been carried out. However, there are several examples that show flaws in the argument that 'because no confounder has been identified we can rule out confounding as a cause of the association'.

**Electrohypersensitivity (EHS)** is covered in several sections (eg, the original Section 8, Section 9). In addition, Section 24, 'Key scientific evidence and public health policy recommendations', highlights a single clinical case study that claims to demonstrate an EHS individual, and discusses two reviews by Johansson that conclude EHS symptoms are caused by EMFs, but it does not mention reviews by Rubin et al (2005, 2010, 2011) that conclude the opposite. The majority of the 16 papers reviewed in Rubin et al 2010 are not covered in BioInitiative 2012, nor are alternative explanations for EHS, such as the 'nocebo' effect, even though some of the relevant papers are cited in Section 9.

**Section 24, 'Key scientific evidence and public health policy recommendations'**, claims that:

At least five new cell tower studies with base-station level RFR at levels ranging from 0.003  $\mu\text{W}/\text{cm}^2$  to 0.05  $\mu\text{W}/\text{cm}^2$  published since 2007 report headaches, concentration difficulties and behavioural problems in children and adolescents; and sleep disturbances, headaches and concentration problems in adults.

The studies are not listed, but from the preceding text they are presumably Buchner and Eger (2012),<sup>25</sup> Eskander et al (2012), Heinrich et al (2010), Thomas et al (2008), Thomas et al (2010) and Mohler et al (2010). An analysis of these six studies shows that two do not permit any meaningful quantitative (or even qualitative) analysis, the findings of three are the opposite of those claimed in the BioInitiative Report 2012, and one reports possible effects but cautions that further studies should be undertaken before forming definitive conclusions.

It is also worth noting that the report does not mention several other relevant studies on the effects of exposures to RF fields from cell sites, which found no effects on sleep quality or other health effects (Berg-Beckhoff et al 2009; Danker-Hopfe et al 2010; Leitgeb et al 2008; Mohler et al 2012).

<sup>25</sup> Cited as 2012 in Section 24, but correctly listed in the references as 2011.

# Appendix F: Terms of reference of the Interagency Committee on the Health Effects of Non-ionising Fields

The Interagency Committee on the Health Effects of Non-Ionising Fields (the Committee) will provide the Director-General of Health with high-quality, independent scientific and technical advice on any potential health effects from exposures to extremely low or radiofrequency fields including:

- the quality and completeness of information on which findings and recommendations have been made
- assessment and review of the impact of research and information published locally and overseas, on policies, guidelines and advice promulgated by the Ministry of Health, Ministry for the Environment or Ministry of Business, Innovation and Employment
- other technical, scientific and epidemiological matters in relation to the extremely low or radiofrequency fields as may be required.

The Committee will report to the Director-General of Health, with copies of meeting notes provided to the Chief Executives of the Ministry for the Environment and the Ministry of Business, Innovation and Employment. Should there be reasonable suspicion of health hazards, or other issues of significance, these will be brought to the attention of joint Ministers. Annual and/or occasional reports will also be provided to joint Ministers.

# Composition of the Committee

The membership of the Committee will include representatives from the following agencies, organisations and sectors:

- Ministry of Health
- Ministry of Business, Innovation and Employment: Energy Safety Service, Workplace Health and Safety, Radio Spectrum Management
- Ministry of Education
- Ministry for the Environment
- public health units
- local government
- academics/scientists
- consumers
- electrical industry: transmission and supply
- telecommunications industry.

Observers may also be in attendance from the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and from the members' agencies or organisations. The Ministry of Health will provide the Chair and secretarial support for the Committee.

**Media policy:** In carrying out their functions as members of the Committee, no member shall make media statements of any kind on behalf of the Committee or about the proceedings of the Committee unless requested to do so by the Director-General of Health. If members wish to discuss media issues, they should contact the Ministry of Health's Corporate Communications Unit in the first instance (tel. 04 496 2008, mobile 021 366 111).

# Appendix G: Background material on extremely low frequency and radiofrequency fields

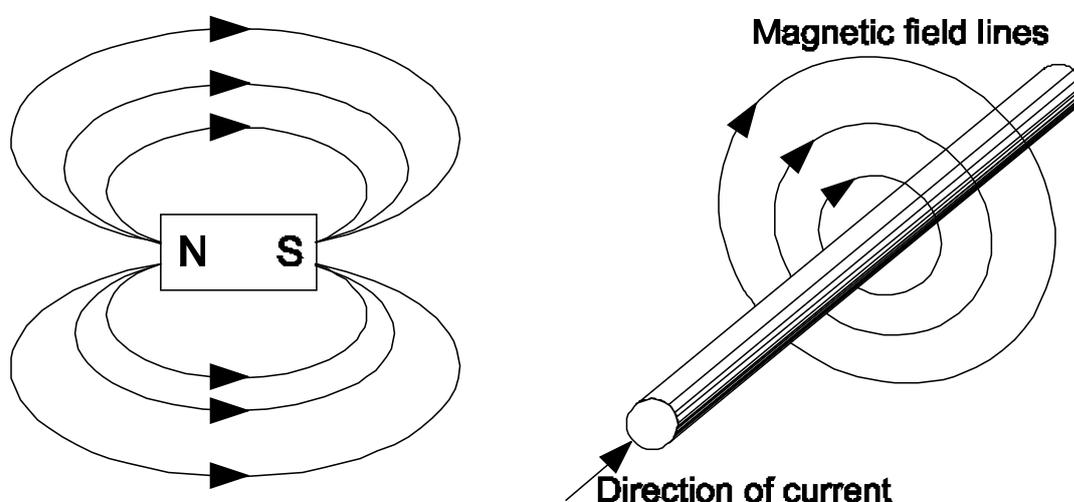
## ELF fields

A small piece of iron held near a magnet will move towards and attach itself to that magnet. The magnet produces a magnetic field around it, which attracts the iron. The field can be pictured by sprinkling iron filings on a sheet of paper and holding the sheet over the magnet.

When the sheet is tapped gently, the filings align themselves in a pattern around the magnet. The Earth is a natural magnet, which enables a compass to be used for direction finding.

Magnetic fields are also produced by an electric current. The magnetic field encircles the current-carrying wire, as illustrated in Figure G1.

**Figure G1: Magnetic field around a magnet (left) and a wire carrying an electric current (right)**



If the current through the wire is not steady, but changes in strength and direction, these changes cause changes in the strength and direction of the magnetic field.

Mains electricity in New Zealand houses, and in almost all power lines, is an alternating current (AC). An alternating current does not flow steadily in one direction, but oscillates backwards and forwards, making 50 complete cycles every second. Therefore, the magnetic field produced by such a current also oscillates at the same rate. This frequency is commonly expressed as 50 Hertz (Hz), and falls into a range referred to as extremely low frequency (ELF). The magnetic fields can be referred to as ELF magnetic fields.

The voltage on a current-carrying wire or electrically charged surface produces an electric field around it. Like the current, the voltage on a cable or appliance carrying mains electricity is not constant but alternates 50 times every second. Therefore, the electric field also alternates and can be referred to as an ELF electric field.

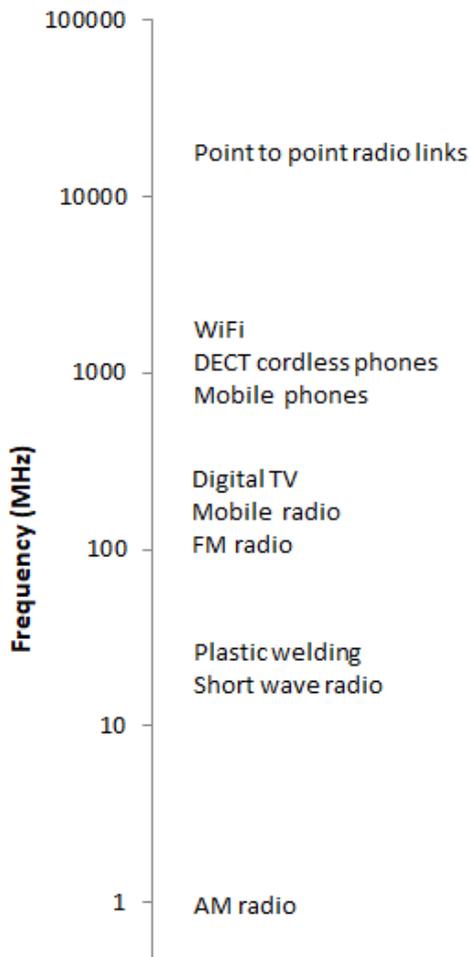
More generally, ELF is taken to cover frequencies up to about 100 kilohertz (kHz). (This was the upper end of the frequency range considered in the WHO (2007) review discussed in Section 2.2.) However, some discussions may only consider a lower maximum frequency. The sources that are usually of most interest in discussions about the health effects of ELF fields are cables or equipment carrying mains electricity at 50 Hz. In recent years, however, other sources of ELF fields have become more common, including induction cooktops and electronic article surveillance equipment (with frequencies of a few tens of kHz). In industry, induction heaters use frequencies of a few kHz.

## RF fields

Radiofrequency (RF) fields are normally understood to include alternating electric and magnetic fields at frequencies greater than 100 kHz, but here too other frequencies may be used to define the lower frequency. The New Zealand radiofrequency field exposure standard, for example, covers frequencies all the way down to 3 kHz. The upper limit is usually taken to be 300 gigahertz (GHz).

Figure G2 shows the main applications of radiofrequency fields as a function of frequency.

**Figure G2: Main applications of RF fields as a function of frequency**



## Terminology

**Radiation** is generally defined as the propagation of energy away from some source, often (but not necessarily) in the form of waves. For example, sound emitted from a loudspeaker could be described as a form of radiation, transporting energy away from the loudspeaker cone in the form of a compressional wave in the air. 'Nuclear' or 'atomic' radiation can involve the emission of energetic sub-atomic particles from unstable atoms.

**Electromagnetic radiation** (EMR) refers to radiation in which the energy is propagated in the form of an 'electromagnetic wave' – linked electric and magnetic fields that have a fixed relationship (in their strengths and orientations) to one another. Unlike a sound wave, which needs a medium in which to travel (such as air or water), an electromagnetic wave can travel through empty space. X-rays, light and microwaves are all forms of EMR.

EMR can be characterised by its frequency or by its wavelength. These two parameters are inter-related: if one is known, the other can be calculated.<sup>26</sup> The parameters refer to the wave-like properties of EMR. Their meaning can be visualised by thinking about

<sup>26</sup> Frequency x wavelength =  $3 \times 10^8$ .

waves in the sea. If you are standing at the end of a pier watching waves come in to the shore, the wave 'frequency' is the number of wave crests that pass you each second. The 'wavelength' is the distance between each crest. The physical properties of EMR, and the way it interacts with the body, depend on its frequency.

**Ionising radiation** is radiation that has sufficient energy to knock electrons out of (ie, 'ionise') atoms. X-rays and gamma rays are types of ionising radiation, as are the particulate radiations of alpha and beta particles that are found in some types of nuclear decay.

**Non-ionising radiation** (NIR) is radiation that does not have enough energy to cause ionisation. Although the term can apply to radiations such as sound and ultrasound, it is often used to refer specifically to electromagnetic radiation with frequencies in the ultra-violet region and below. Light and microwaves are both types of non-ionising electromagnetic radiation (NIEMR).

The term 'non-ionising radiation' is also applied to electric and magnetic fields that do not constitute EMR according to the usual definition of radiation. An electric current flowing through a wire creates a 'magnetic field' around the wire, which is similar in its nature and properties to the magnetic field found around a bar magnet. The voltage on the wire creates an 'electric field'. If the current through the wire changes in strength and direction, this is reflected in changes in the strength and direction of the magnetic field. Changes in the voltage cause changes in the electric field.

However, these electric and magnetic fields do not constitute EMR, as their strengths and orientations are unrelated, and they do not transport energy away from the electric current that causes them. Technically, these fields are referred to as 'reactive' or 'fringing' fields.<sup>27</sup> This distinction becomes important at lower frequencies, such as those at which mains electricity is transmitted.

**Electromagnetic field** (EMF) is an umbrella term usually used to include both ELF and RF fields.

**Radiofrequency (RF) fields** are electromagnetic fields at radio frequencies (usually taken to be from about 100 kHz to 300 GHz).

**Extremely low frequency (ELF) fields** are electromagnetic fields at low frequencies (usually taken to be from about 1 Hz to about 100 kHz).

**Microwaves** is a term used to talk about radiofrequency fields at frequencies greater than 300 megahertz (MHz) (some people put the lower threshold for microwaves at 1,000 MHz = 1 GHz).

<sup>27</sup> True EMR is produced by the acceleration of electric charges, whereas the reactive magnetic field is related to the velocity of the charge. Any source of true EMR will also produce some reactive fields, but normally these fields only extend about one wavelength away from the source. For example, around an FM radio transmitter broadcasting at a frequency of 100 MHz (wavelength 3 metres), reactive fields can be detected up to about 3 metres away from the antenna. A measurement of the electric or magnetic fields within 3 metres of the antenna is not representative of the power being radiated. Only measurements more than 3 metres from the antenna give a true indication of the amount of the radiated power. This distinction is perhaps most important when considering power lines. Very often, people are said to be exposed to 'power line radiation' or 'magnetic radiation', when in fact no radiation is involved. The magnetic fields measured around power lines do not transport energy away from their source, and their nature and effects are not the same as 'true' EMR. If they did represent true radiation (ie, propagation of energy away from their source), this would cause a significant loss of the electrical energy being transmitted along a power line.