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Interagency Committee on the Health Effects of Non-ionising Fields

Report to Ministers 2022

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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 to Ministers* 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 that are of interest or exemplify work carried out in particular areas.

This 2022 publication updates the report published in 2018 and includes the assessment of several new national and international reviews of the research. New sections covering fifth-generation (5G) technology and how research data is assessed have been added. While much new data has been reported, the overall conclusions are 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 of 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. Some recent studies indicate that the reported associations have become weaker over time.

This work has confirmed, however, that even if magnetic fields have some effect, they 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.

Research published since the 2018 *Report to Ministers* suggests that current exposure recommendations do not need to be revised. These recommendations follow guidelines published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), an international scientific body recognised by the WHO for its

independence and expertise in this area. The Committee notes, however, that ICNIRP is currently reviewing its low-frequency exposure guidelines.

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 2011.¹

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. Animal studies provide limited evidence of an effect of RF fields on cancer, and the significance of some recent large studies is disputed.

5G, the latest generation of mobile phone technology, was introduced in New Zealand in late 2019 and there are now several hundred sites around the country. Like previous mobile phone technologies, it uses radio waves to link devices with base stations. The large body of existing research on the health effects of RF fields, and the protection standards derived from that research, also cover exposures to RF fields from 5G. Exposures from 5G are similar to those from existing mobile phone technologies.

RF research is continuing in a number of areas, but data currently available provides no clear or persuasive evidence of health effects caused by exposures that comply with limits in the current New Zealand Standard NZS 2772.1. This standard is based on guidelines published by ICNIRP in 1998. The Committee notes that ICNIRP published an updated version of its guidelines in 2020. The basis of the 2020 guidelines is very similar to the 1998 version on which the New Zealand Standard is based, and ICNIRP has said that the 1998 version remains protective for current commercial applications of RF fields. Important changes, however, have occurred at higher frequencies that will be used more as technology evolves, particularly for personal devices. The Committee notes that the Australian RF exposure standard has recently been amended and is now based on the ICNIRP 2020 guidelines, and agrees with the Ministry of Health statement that compliance with either the ICNIRP 2020 guidelines or the revised Australian standard would provide protection at least equivalent to that offered by NZS 2772.1. The Committee recommends that at some stage New Zealand also moves to recommend limits based on the ICNIRP 2020 guidelines.

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

Overall conclusions

On the basis of findings from recent research, the Committee concludes that current policies and recommendations still protect health, but advises that the RF exposure recommendations should be updated to be consistent with the ICNIRP 2020 guidelines. This update should also be reflected in any legislation that is based on Ministry of Health recommendations, such as the Resource Management (National Environmental Standards for Telecommunication Facilities) Regulations 2016.

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

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 (ELF) electric and magnetic fields. The scope was extended to include radiofrequency (RF) fields in 2001, at which time the Committee became a Ministry of Health technical advisory committee. The current terms of reference and Committee membership are presented in Appendix G.

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.

RF fields make up the radio waves produced by a wide range of telecommunications equipment. 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.² RF fields carry energy away from the transmitter, whereas ELF electric and magnetic fields are fixed in place around whatever produces them. The electrical properties of the body vary markedly between extremely low frequencies and radiofrequencies, which is why ELF and RF fields do not interact with it in the same way.

For some background material on ELF and RF fields, see Appendix H. Further information is also available on the Ministry of Health's (the Ministry's) website.³

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

³ 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 one was published in 2018 (Interagency Committee on the Health Effects of Non-ionising Fields 2018).

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 2018 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.⁴ Rather than taking that approach, this *Report to Ministers* summarises the principal findings of these overseas reviews, concentrating on those published within the past 10 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 of publication for research and reviews included in this report was 31 December 2021.

A persistent feature of electromagnetic field (EMF) research (both ELF and RF) has been the poor quality of much of the published work. While peer review should provide for a minimum standard of quality, in practice it may not consider all the relevant aspects of the work described. The Swedish Radiation Safety Authority, for example, in its 2019 report in its series of annual reviews of recent research (SSM Scientific Council on Electromagnetic Fields 2019), commented that 50% of the studies on cell cultures exposed to RF fields were not considered in its analysis due to the 'scanty quality of the research'. The current report includes a new appendix (Appendix F) discussing how scientific research, both individual studies and the whole body of work, is assessed in order to draw valid conclusions.

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

⁴ 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 recommends the use of guidelines published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP 2010) to manage public exposures to ELF fields. ICNIRP is an independent scientific body, recognised by the WHO for its independence and expertise in this area through its Framework for Engagement with Non-State Actors process. ICNIRP's 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 25 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 (μT)⁵ for the magnetic field and 5 kilovolts per metre (kV/m) for the electric field. For occupational exposures, the reference levels are 1,000 μT and 10 kV/m respectively.

The limits set for people exposed occupationally are different from those set 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 recommends that the occupational limits should be applied only to people such as power line workers 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 on exposures from other agents. The recommendation recognises that it is impossible to prove that any agent is absolutely safe, and that in some areas further research is being undertaken to deepen 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 on the Ministry's website.

2.2 Radiofrequency fields

The Ministry 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 ICNIRP published in 1998, which it derived from a

⁵ The microtesla (μT) 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). $1 \mu\text{T} = 10 \text{ mG}$.

careful review of the health effects research and reaffirmed in 2009 (ICNIRP 2009b) following a review of more recent research in this area (ICNIRP 2009a). ICNIRP published revised guidelines in 2020 (ICNIRP 2020b). The underlying basis for these limits is essentially the same as for the 1998 guidelines, and the main change is to introduce some refinements for brief or intermittent exposures at high frequencies. ICNIRP considers that the 1998 guidelines are still protective for current commercial applications of radiofrequency fields, but recommends that countries adopt the new guidelines in order to ensure protection for potential new applications. The Ministry has reviewed the ICNIRP 2020 guidelines, along with the revised Australian RF field protection standard RPS S-1 (ARPANSA 2021), which is based on the new guidelines, and advises that compliance with either would provide protection that is the same as, or better than, that offered by NZS 2772.1:1999.

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 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 assume that exposures could occur all day, every day and 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.⁶ 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.⁷

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 in the field.

Compliance with the reference levels ensures compliance with the basic restrictions, and in many situations the reference levels 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

⁶ 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.

⁷ 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.

analysis is required before compliance can be verified. The reference levels vary with frequency, and are at their lowest at frequencies of around 100 megahertz (MHz).

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 RF transmitters are being installed, 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 (cellsites), 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's 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. These are discussed in Appendix A.

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 exposure 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 μT . 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. Therefore 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 5.5) should be implemented to protect against the established acute effects of exposure to ELF 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.

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- and pooled analyses
- neurodegenerative diseases (eg, Alzheimer's disease, amyotrophic lateral sclerosis).

A key part of this work has been to try to understand the origin of the association between the increased risk of childhood leukaemia and chronic exposures to ELF magnetic fields greater than 0.3–0.4 μT . In particular, it has explored whether the fields or some other factor are responsible for the association.

Epidemiological studies of childhood and other cancers

Several epidemiological studies of childhood leukaemia incidence in relation to magnetic fields have been carried out since two major pooled analyses⁸ of similar research were published in 2000. These include large studies (either entirely new or updates of previous work) from the United Kingdom, Italy, Denmark and the United States of America. The findings from these studies have been included in several reviews and meta- or pooled analyses. Overall, these findings lead to the same

⁸ A pooled analysis combines the raw data from several studies. This approach is in contrast to a meta-analysis, which uses the study results, rather than individuals' data. Pooled analyses are generally considered to provide more reliable results.

conclusions about childhood leukaemia as the 2007 WHO review. Some studies (eg, Swanson et al 2019), however, suggest that the magnitude of any risk has decreased over time. The most recent pooled analysis (Amoon et al 2022) includes data on over 22,000 cases of childhood leukaemia from four studies published since 2010. It concludes:

Our results are **not** in line with previous pooled analysis and show a decrease in effect to no association between MF and childhood leukemia. This could be due to methodological issues, random chance, or a true finding of disappearing effect.

Yet this was not the conclusion of the Health Council of the Netherlands (2018) when it conducted a meta-analysis of the studies (including the four examined by Amoon et al) that it considered had the most comprehensive histories of magnetic field exposures of children. It found 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 to 0.4 μT – similar to the findings of the earlier (2000) pooled analyses.

The possibility that parental exposures to ELF fields might affect childhood leukaemia risks has also been investigated. A pooled analysis of 11 studies investigating this (Talibov et al 2019) and a large residential study (Auger et al 2019) both concluded that there was no relationship.

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

The Advanced Research on Interaction Mechanisms of electroMagnetic exposures with Organisms for Risk Assessment (ARIMMORA) research programme, funded by the European Union (EU), 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 based on existing research and the new findings 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).

Some further work on adult cancers has also been published. Research on breast cancer (Q Chen et al 2013; Li et al 2013) generally supports the WHO (2007) conclusion that the disease has no association with ELF fields. An important source of information on ELF fields and adult cancers in the WHO (2007) review comes from studies of electrical utility workers. Sorahan (2014, 2019) has looked at cancers in UK electricity workers and concluded that there is no good evidence for an effect of ELF fields.

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. The review 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 several meta-analyses of occupational studies (eg, Huss et al 2018; Jalilian et al 2020). A difficulty in analysing these studies is that they have used a range of methods to assess exposures, including job titles, measurements, self-reports and job-exposure matrices. Results still show considerable heterogeneity. A meta-analysis of residential studies of ALS (Filippini et al 2021) found scant evidence of an association, but commented that the data was too limited to permit a sophisticated analysis.

Thresholds for perception of magnetophosphenes

A research group at the Lawson Health Research Institute, Canada has investigated the onset of magnetophosphene⁹ 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 millitesla (well above the reference level for the public of 200 microtesla), and the sensitivity for detection is, as supposed, inversely proportional to frequency (Legros et al 2014). 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.

3.4 Overseas reviews

Only one review devoted exclusively to ELF fields and health (ANSES 2019) has been published since the 2018 *Report to Ministers*, but ELF fields have been considered in annual updates published by the Swedish Radiation Safety Authority's (SSM's) Scientific Council on Electromagnetic Fields (see Appendix C for summaries). Both of these groups note that open questions remain over the childhood leukaemia data and that, while some research on neurodegenerative diseases reports associations, no clear pattern emerges.

⁹ 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.

3.5 Future work

A few novel approaches to resolving the childhood leukaemia question have been suggested. The intention in doing so 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.¹⁰ Areas covered include neurodegenerative diseases, childhood leukaemia, miscarriage, corona discharge and risk communication.

ICNIRP (2020c) published a review identifying areas in which further research would assist with the future development of ELF exposure guidelines. The areas identified included pain from contact currents, neurodegenerative diseases, childhood leukaemia (investigating mechanisms and using new animal models, rather than further epidemiological studies) and dosimetry. ICNIRP has also established a task group to develop updated low-frequency guidelines.

3.6 Conclusions

Overall, the picture is still largely unchanged since the publication of the WHO (2007) review. The possibility that long-term exposure 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 exists, ELF magnetic fields would be responsible for only a small fraction of childhood leukaemia cases. Recent findings tend to weaken the possibility that a link exists. Research on possible links with neurodegenerative diseases has provided inconsistent results.

¹⁰ For more information, see www.bfs.de/EN/bfs/science-research/bfs-research-programme/grid-expansion/grid-expansion_node.html

4 Research on radiofrequency fields

4.1 Introduction

Applications and uses of technology incorporating radio transmitters have grown rapidly 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 or three such reviews are published every year (see Section 4.7 and Appendix D for summaries).

4.2 RF and cancer

Mobile phones and brain tumours

Most cancer research has focused on 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 epidemiological investigations (the Interphone study and the Hardell group studies), as well as some other case-control and cohort studies, and cancer registry studies. Some meta-analyses have also been conducted. Animal studies have been used to provide experimental evidence.

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 Study Group (2010) 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 cumulative call times. However, the researchers noted biases in the data (eg, 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, following different methods, that looked at glioma location in relation to the part of the brain that received the highest RF exposure. One of these studies (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 increase 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 in results between the Hardell and Interphone studies (which included a research centre in Sweden). However, the greater quality control and accompanying data validation studies carried out by the Interphone Study Group have been noted.

Cohort studies

A continuing study has followed a Danish cohort of some 420,000 people who signed a mobile phone subscription between 1982 and 1995. Findings published in 2002 and 2011 show no increased risk of brain tumours. This study has several strengths and weaknesses (see, eg, 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, carried out in the United Kingdom, 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).

A further large cohort study (COSMOS, discussed further in Section 4.10) is now in progress but has not yet published any findings on brain tumours.

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; Deltour et al 2012, Scandinavia; Karipidis et al 2021a, Australia; Kim et al 2015, New Zealand; Little et al 2012, United States of America; Nilsson et al 2019, Sweden; Villeneuve et al 2021, Canada). 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 latencies¹¹ greater than around 15 years.

Other cancers

Fewer epidemiological studies of other cancers have been carried out. Recent examples include work by Safari Variani et al (2019), who carried out a systematic review and meta-analysis of exposures to radar and cancer risk, and Gao et al (2019), who published their first findings from a cohort study of cancer in British police officers and staff using Terrestrial Trunked Radio (TETRA). Neither found evidence of an association. Luo et al (2019) looked at thyroid cancers in relation to cellphone use and found no significant associations.

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. (For a summary of the IARC classification scheme used at the time of this evaluation, see Appendix B.) 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 (Samet et al 2014), 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

¹¹ Periods between when an exposure causing or promoting cancer first occurred and the appearance of the cancer.

difficult to communicate and did not fit well with media seeking a more definitive position.

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.

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 applies a very strict technical definition to an everyday term ('possible') that is normally applied very loosely, so it is not 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 strength of the evidence suggesting that there is a hazard, and it considers this evidence to be 'uncertain'.

Section 4.7 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 (second-generation, 2G) or older-generation mobile phones, which typically operate at powers 50–100 times greater than third-generation (3G) or fourth-generation (4G) phones, and so produce exposures to the head that are correspondingly higher. For example, widespread rollout 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 and 4G service over the whole country, and only one still operates a GSM network.

In 2019 an IARC Advisory Group recommended that RF fields be re-evaluated in the 2020–2024 period (IARC 2019b), as several new epidemiological and animal studies have been published since 2011, and the results of other large epidemiological studies should be available soon. This new evaluation will follow a revised protocol published by IARC in 2019 (IARC 2019a), which emphasises applying the principles of systematic review to the identification, screening, synthesis and evaluation of the research data. The new protocol also makes the role of mechanistic studies in the final evaluation more explicit and removes the Class 4 'Probably not carcinogenic' category.

In the meantime, however, the IARC 2020 *World Cancer Report* commented that:

Most of the epidemiological research does not support an association between mobile phone use and tumours occurring in the head, which is the body part with the highest exposure to radiofrequency electromagnetic fields. In studies reporting positive associations, it is difficult to exclude various forms of bias, such as recall bias in retrospective exposure assessment.

United States National Toxicology Programme study

The final reports of a large US National Toxicology Programme (NTP) study investigating carcinogenicity in rats and mice exposed to GSM- and CDMA-modulated mobile phone signals were published in late 2018 (NTP 2018a, 2018b). The animals were exposed for nine hours per day, at three different exposure levels over periods of up to two years. The rats were exposed at 900 MHz and the mice at 1,900 MHz. A large number of end points, including the occurrence of cancers and cancer-related genetic damage in various organs, was investigated, with results from the exposed animals compared with those from unexposed controls.

The NTP concluded that there was 'clear evidence'¹² of carcinogenic activity of RF fields in the rats. This was based on an increased incidence of malignant schwannomas in the hearts of male rats for both GSM and CDMA modulations at the highest exposure levels used. The NTP also considered that there was 'some evidence' of carcinogenicity based on an increased incidence of malignant gliomas in the male rats from both modulations, and from increased tumours in the adrenal glands of rats exposed to GSM.

On the other hand, for female rats no findings were considered to show 'clear' or 'some' evidence of carcinogenicity and only 'equivocal' evidence was found in the male and female mice.

The NTP noted that the RF levels used, and exposure durations, were greater than people would experience from mobile phone use, and the whole body was exposed rather than localised areas of the animal. It cautioned against extrapolating the results to mobile phone use. The US Food and Drug Administration (FDA), which proposed the study, concluded that it does not demonstrate that cellphones cause cancer.¹³

The NTP study has several strengths. It used large numbers of animals, followed good laboratory practice and exposed animals over their entire lives. However, several weaknesses are also apparent (see, eg, Elwood and Wood 2019a; ICNIRP 2020a), although these are contested (Melnick 2020). The exposures used were intended to prevent significant increases in the animals' temperatures but there are reasonable grounds to consider that the male rats' temperatures were in fact affected, and that the resulting heat stress could account for the increased cancers (Kuhne 2020). In addition, survival of male rats in the unexposed control group was poor compared with the exposed male rats, making comparisons between exposed and unexposed groups difficult. Because a large number of end points was examined, many positive results would be found by chance,¹⁴ but no correction was made for this. While heart schwannomas are extremely rare in humans, the NTP considered them significant because they are related to acoustic neuromas (a form of schwannoma), which some epidemiological studies suggest are more common in cellphone users. However, this

¹² 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.

¹³ www.fda.gov/news-events/press-announcements/statement-jeffrey-shuren-md-jd-director-fdas-center-devices-and-radiological-health-national

¹⁴ This is intentional, as the purpose of the NTP studies is to find possible harmful agents that can then be subjected to further research.

argument is not supported by the finding of no significant increases in schwannomas in any other organs or in the total number of schwannomas.

The NTP has started a second phase of work, which will further characterise effects, address some of the issues raised by peer review and investigate interaction mechanisms. This will use new exposure chambers and more sophisticated monitoring of the animals. Korean and Japanese researchers have also started a joint programme to explore the findings of the NTP study. Results are expected in about 2023.

A study similar to the NTP work, but using much lower exposures and only GSM modulation at 1,800 MHz, was also published in 2018 (Falcioni et al 2018). This study exposed male and female rats to GSM signals at 1,800 MHz, at much lower exposures than the NTP. This study also reported a significant increase of heart schwannomas in male rats with the highest exposures. While this study is sometimes reported as supporting the NTP findings, the NTP only found significant increases of heart schwannomas at exposure levels 60 times higher than those used by Falcioni et al; it found no such increases at levels 15 and 30 times higher (which would have been expected if the results were consistent).

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 well-controlled, well-conducted double-blind studies 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, eg, Baliatsas et al 2012; Rubin et al 2011). Experimental evidence suggests a nocebo 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 such as 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 in the Netherlands

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 are 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. A review of methodological limitations of the research in this area (Schmiedchen et al 2019) concluded many of the studies had limitations that could have resulted in false positives or false negatives, but the more methodologically sound studies do not suggest that the symptoms are related to electromagnetic field exposures.

While the research seems to discount electromagnetic field exposures as the cause of EHS, there is still no clear idea of how people develop the symptoms in the first place. Dieudonné (2020) examined three hypotheses on how EHS arises – the effects of electromagnetic fields, false beliefs that promote a nocebo effect and the suggestion that EHS is a coping strategy for pre-existing conditions – but concluded that none was totally satisfying. A new approach to research in this area has been proposed (Ledent et al 2020).

Elwood (2020) reviewed the occurrence of symptoms in a New Zealand context. He noted that the nature and incidence of symptoms reported in relation to RF fields were similar to those reported by a random sample of New Zealanders. Initial findings from the COSMOS prospective cohort study (discussed in Section 4.10) suggest that headaches, hearing loss and tinnitus are not related to cellphone use.

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 and Olsen 2016).

4.4 Children and adolescents

The possibility that children might be more sensitive to the effects of RF fields was highlighted by the report of the UK Independent Expert Group on Mobile Phones (2000) (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). A WHO workshop in 2011 also addressed the subject (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 an adult's head does, 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 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. This is discussed in the ICNIRP 2020 guidelines, but considered not to be of concern because of the very specific exposure conditions required (eg, a three-year-old standing upright with hands above the head for 30 minutes), the conservatism built into the limits and the fact that this type of exposure will not have any health effects.

An initial 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. The more comprehensive international MOBI-Kids study (Castano-Vinyals et al 2021), which was carried out in 14 countries (including New Zealand, where the research group has received funding from the Health Research Council and Cure Kids), also found no evidence of a causal association between mobile phone use and brain tumours in young people. The researchers noted, however, that residual biases meant that a small increased risk could not be ruled out.

Overall, studies investigating childhood cancer incidence near broadcast transmitters suggest there is no increased risk associated with increased exposure, but these studies would be unlikely to pick up a small increased risk, and exposures are quite low.

Other research on development, cognition and related areas has, overall, found that children are not especially susceptible to any effects of RF fields. In a review on the influence of RF fields on children's brain function, the Health Council of the Netherlands (2011) 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. A review by the Julich Research Centre (Wiedemann et al 2009) found that the existing scientific evidence did not suggest children's health is affected by RF from mobile phones or cellsites, but that evidence in some areas was limited and further research was needed. The ANSES (2016) review found that evidence is insufficient to draw firm

conclusions in many areas, but it considered that existing exposure limits do not need 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

Several studies have investigated the effects of exposures to mobile-phone-like signals on the brain's electrical activity as 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-like signals before sleep. The changes are small (eg, they have been described as smaller than those that occur after blinking) and seem not to have any effects on sleep quality or implications for health. There also appear to be considerable differences between individuals.

Findings have been inconsistent. Recent work at the University of Wollongong and elsewhere suggests that some underlying thermal mechanism may be at work (Loughran et al 2019), and also that inconsistent findings and inability to reproduce results may be due to differences in experimental protocols (Dalecki et al 2021; Danker-Hopfe et al 2019). The Wollongong group has suggested that cognitive effects may also 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 Exposures to RF fields

A large number of studies investigating environmental exposures to RF fields has been published in recent years. These were mainly carried out in Europe, but many of the findings should be representative of what would be found in New Zealand as the technologies used here are the same as in other countries. Various methods have been used to assess exposures, including spot measurements in selected locations, long-term measurements at fixed sites and personal measurements in which individuals wear a small personal exposure meter that makes continuous exposure measurements throughout the day. There are advantages and disadvantages to each of these approaches.

Jalilian et al (2019) published a systematic review of 26 European exposure studies. Exposures found in different environments are summarised in Table 1.

Table 1: Exposures reported by Jalilian et al (2019)

Environment	Mean exposures (% public limit in NZS 2772.1:1999)¹⁵	Comments
Homes and schools	Typically <0.005%	Sources of exposure mostly unidentified. Where they were identified, most contributions came from cellphone downlink or uplink.
Rural/suburban residential areas (outdoors)	0.0003–0.004%	Mainly cellphone downlink.
Urban areas (outdoors)	0.003–0.05%	Mainly cellphone downlink.
City centres	0.01–0.1%	Mainly cellphone downlink.
In transport (cars, buses, trains, trams)	0.0001–0.03%	Mixture of cellphone downlink and uplink. Exposures up to 0.2% in railway stations.

The authors compared their findings with similar work carried out before 2012 and concluded that no major changes had occurred in that time.

There is no comparable New Zealand data. While some mobile phone network operators commission measurements,¹⁶ these are all made around cellsites, while the studies reviewed by Jalilian et al were not targeted in this way.

Exposures from WiFi are discussed in Section 6.2.

4.7 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 15 years, mobile phone use has no effect on brain tumour incidence, and some suggest that research reported since the IARC evaluation has not confirmed any cancer risk. Links to recent reviews are on the Ministry's website.

The BioInitiative Report (BioInitiative Report 2007), 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.

¹⁵ These exposure studies normally report exposures in volts per metre (V/m). These have been converted to a percentage of the public reference level assuming that exposures are predominantly at 900 MHz. This would overestimate exposures from some sources (DECT cordless phones, WiFi, higher-frequency bands used by cellsites). Exposures from broadcast transmitters would be underestimated, but these mostly made minor contributions to the total.

¹⁶ Results are available on the Ministry's website: www.health.govt.nz/our-work/environmental-health/non-ionising-radiation/independent-cellsite-monitoring

4.8 Study quality

The quality of some published studies investigating potential effects of exposures to RF fields on health has long been a concern. In its annual reviews of the research, the Swedish Radiation Safety Authority's Scientific Council on Electromagnetic Fields has started to include an appendix listing studies that were excluded from its analysis because they did not satisfy basic quality criteria.

Vijayalaxmi and Prihoda (2018) analysed 225 studies of genetic damage in mammalian cells exposed to RF fields, scoring each study according to how many of four basic quality control measures it satisfied. They found that the more measures it satisfied, the less likely the paper was to report genetic damage. If studies were weighted according to the quality control measures adopted, they showed little, if any, effect of exposures to RF fields.

A subsequent paper (Vijayalaxmi and Prihoda 2019) found that studies funded by industry were more likely to include these quality control methods than studies funded by government. The authors noted, however, that this observation should be treated cautiously as a far greater percentage of studies acknowledged government funding than those acknowledging industry funding.

A third paper (Vijayalaxmi and Foster 2021) examined studies carried out at frequencies above 6 GHz and also noted significant weaknesses in many of them. The authors proposed that more funding should be made available to ensure good-quality research was carried out and that stricter review policies should be implemented by scientific journals.

The same types of problem have been evident for many years and constitute a considerable waste of research funding and effort (and, in some cases, experimental animals) that serve only to distract rather than illuminate understanding. A further problem has been a tendency to investigate a very wide range of end points and exposure conditions, with little or no communication or coordination between different research groups (Bernabo et al 2017). While several organisations (notably the WHO) have periodically published research agendas that highlight areas considered to be research priorities, unfortunately not all researchers pay attention to these, or perhaps they are not even aware of them.

4.9 5G

Characteristics

In many respects, fifth-generation (5G) radio signals resemble those used by 4G, and in fact the differences between 4G and 5G are fewer than between previous generations. There are a few key changes in their characteristics.

- 5G permits using a much greater signal bandwidth for radio transmissions than 4G. (The bandwidth can be visualised as the diameter of the pipe used to deliver the data – the wider the pipe, the faster the data can be delivered.)

- While 5G sites in New Zealand currently use frequencies similar to those used by 4G, the 5G specifications also permit the use of much higher frequencies. (The frequency of the signal can be thought of as where you would have to tune a radio receiver to pick it up.) The higher frequencies proposed are similar to those that have been used for many years for other applications, such as radar and point-to-point radio communication links using dish antennas.
- 5G will normally use beam-forming antennas (sometimes referred to as ‘active antennas’).¹⁷ Conventional cellsite antennas produce a single fan-shaped beam covering a sector about 120 degrees wide. Regardless of where the end user of the radio signal is, the radio beam is sent to the entire area served by the antenna. Beam-forming antennas produce a larger number (say, 48) of narrow beams that only cover a small area around the end user. Figure 1 illustrates this.

Figure 1: Conventional antenna (left) and beam-forming antenna (right)



The conventional antenna transmits to the same area regardless of which devices actually receive data, whereas the beam-forming antenna sends the signal only in directions that need it. Beams switch off when not in use. Depending on the specific implementation, a site could transmit on several beams simultaneously, with the transmitter power divided between them all.

As noted above, 5G sites in New Zealand currently operate at frequencies around 3.5 GHz, which is similar to those used by existing cellsites. Within a few years, it is likely that higher frequencies around 26 GHz (sometimes referred to as millimetre waves – mmWaves) will also be used. Similar frequencies have been used for other applications such as radar and point-to-point communication links for many years, and they are within the range covered by the New Zealand exposure standard. mmWave sites will probably be limited to locations with many people, especially outdoors, for example at a sports stadium, in city centres or possibly in large indoor areas. mmWaves are not well suited to suburban areas because building materials largely block them. A fixed wireless broadband service would probably require external antennas to be effective.

Lower frequencies may also be used in future. These are less likely to use beam-forming antennas.

¹⁷ Beam-forming is used to a limited extent by some 4G sites. 5G sites initially deployed in New Zealand did not use beam-forming antennas, but most new installations use them.

Exposures

Measurements near 3.5 GHz 5G sites in New Zealand have shown that 5G does not add much to existing exposures (Gledhill 2020a, 2020b). Exposures due to 5G with a heavy traffic load (during a download speed test, or with the 5G transmitters set to operate continuously at full power) were all less than 1% of the public limit in the New Zealand exposure standard and typically accounted for less than one-fifth of the total exposure. In normal operation (ie, if the site is not deliberately loaded), exposures are considerably lower.

Measurements in other countries have found similar results.

Measurements on 5G mmWave small cells in Australia have found that most exposures are less than 0.1% and all are less than 1% of the exposure limit.

Health effects

None of the characteristics of 5G radio systems is particularly distinctive. As mentioned previously, the signal modulation (the way information is encoded onto the radio signal) resembles that used by 4G. Research has not suggested that health effects relate to modulation.¹⁸ For these reasons, the research already undertaken on health effects of exposures to RF fields is as applicable to 5G as to other radio signals, and exposure limits derived from that research should also apply to 5G. To date, no interactions have been discovered that would operate at mmWave frequencies but not at the frequencies currently used by mobile phone networks and broadcast transmitters.

A common misconception is that higher-frequency signals could carry more energy and so be more harmful. In fact, the most important parameter is the intensity of the radio wave. Frequency only affects where the energy in the radio signal is absorbed. At 26 GHz the energy is almost entirely absorbed in the first millimetre or so of the skin (some of the energy is also reflected by the skin), whereas at 3.5 GHz the energy is absorbed at depths up to about 20 mm.

There have been several reviews of research relevant to 5G and health, covering both 3.5 GHz frequencies and mmWaves.

In 2019 the IEEE published a revised version of its C95.1 standard (IEEE International Committee on Electromagnetic Safety (SCC39) 2019). Annex C.8 reviews the research literature at frequencies between 6 and 300 GHz (which includes mmWave frequencies). The basis of the exposure limits set in the C95.1 Standard is the same as that of NZS 2772.1 and ICNIRP (2020b), and the recommended limits at mmWave frequencies are also very similar.

The Health Council of the Netherlands (2020) and the French Agency for Food, Environmental and Occupational Health & Safety (ANSES 2022) have also published reviews of the research relevant to 5G exposures (at frequencies up to 3.5 GHz and in

¹⁸ Unless the radio signal is made up of extremely short, very intense pulses, which would not be permitted by the exposure standard.

the mmWave bands). For summaries of these reports, see Appendix D. Both bodies concluded that evidence currently available gave no reason to believe that 5G in the 3.5 GHz and lower-frequency bands would affect health any differently to other radio signals. The Health Council of the Netherlands suggested that exposures should be monitored. In the mmWave band around 26 GHz, however, both bodies considered that the evidence is insufficient to draw firm conclusions on whether there may be any effects other than those due to heating. The Health Council of the Netherlands recommended using the ICNIRP 2020 guidelines as the basis for exposure policy but introducing a requirement to keep exposures as low as reasonably achievable. It also recommended against using the 26 GHz band for 5G until further research was available. ANSES noted that exposures in the 26 GHz band are likely to be low, but that this should be confirmed once trials start in this band.

In a 'pragmatic review of in vivo and in vitro research between 6 and 100 GHz', Simko and Mattsson (2019) found no consistent relationship between exposure intensity, time or frequency and reported effects. They concluded that the studies gave no clear evidence of health effects at exposures complying with limits, due to contradictory findings, and no clear indication of non-thermal effects, but few of the studies met basic quality criteria.

Karipidis et al (2021b) and Wood et al (2021) (from the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and Swinburne University respectively) published two papers reviewing research on the effects of low-level exposures (meaning below recommended limits) at frequencies greater than 6 GHz. The first paper provided a general overview, and the second undertook a meta-analysis of the 107 in vivo and in vitro studies meeting the frequency and exposure level criteria. The general overview also considered the findings of 31 epidemiological studies investigating effects of exposures to mmWave radar and various health outcomes. The reviews examined the quality of the studies, whether results had been replicated, what mechanism might be involved and whether greater exposure led to a greater effect.

Many of the studies were of poor or average quality, and the better-quality studies were less likely to report adverse effects. Adverse effects were also not independently replicated and mostly came from a small group of laboratories producing studies judged to be of poor or average quality. Adverse effects were not consistently shown across in vivo, in vitro and epidemiological studies. The size of any effect reported did not increase with exposure; in fact, the inverse was found. Finally, no mechanism showing how low-level mmWaves might cause adverse effects had been identified.

Karipidis and Wood acknowledge that further research, of better quality, is needed but while the Health Council and the ANSES reviews are reluctant to draw conclusions about health effects of mmWaves, particularly in respect of the 26 GHz band, Karipidis and Wood conclude that there is no consistent evidence to suggest biological effects from mmWaves at levels below the ICNIRP occupational limits. Since general public limits are 10 times lower than the occupational limits, the evidence for effects at these levels is even weaker.

Summary

5G services at 3.5 GHz are now available in all the main centres of New Zealand and many smaller centres as well. The initial public concern about 5G appears to have decreased considerably over the past year.

Measurements have shown that 5G does not add appreciably to exposures from cellsites. Research has not found good reason to doubt the protection offered by existing exposure limits.

The Ministry has a *5G and health* information sheet¹⁹ and *5G questions and answers* page²⁰ on its website. The Office of the Prime Minister's Chief Science Advisor has also posted extensive material about 5G on its website.²¹ The WHO has material on its website²² too.

4.10 Future work

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

An Australian research programme, which is funded by a levy on the telecommunications industry, is now being coordinated by ARPANSA. ARPANSA will conduct some of the work itself, which will include conducting new RF exposure surveys, updating ARPANSA's RF exposure facility, providing information on RF fields and health and carrying out research. In addition, ARPANSA will promote, coordinate and fund research by others, following ARPANSA's research framework. The framework prioritises research that fills knowledge gaps and addresses areas of public concern. The first call for research proposals, released in September 2021, covers research that will develop the evidence base for exposures at frequencies above 6 GHz, relevant to emerging technologies such as 5G, and its relationship to health and wellbeing. The programme is described in more detail on the ARPANSA website.²³

The Cohort Study of Mobile Phone Use and Health (COSMOS), which started in six European countries in 2007, is now 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 so it does not have to rely on the study participants' memories. The first results showed no relationship between RF from mobile phones and tinnitus, headaches and hearing loss in participants from Sweden

¹⁹ www.health.govt.nz/your-health/healthy-living/environmental-health/radiation-environment/cellsites-and-5g

²⁰ www.health.govt.nz/your-health/healthy-living/environmental-health/radiation-environment/cellsites-and-5g/5g-questions-and-answers

²¹ www.pmcsa.ac.nz/our-projects/hot-topics/5g-in-aotearoa-new-zealand/

²² www.who.int/news-room/q-a-detail/radiation-5g-mobile-networks-and-health

²³ www.arpansa.gov.au/research-and-expertise/electromagnetic-energy-program/arpansa-eme-program-action-plan-2020-2024

and Finland (Auvinen et al 2019) and no effects on sleep quality (Tettamanti et al 2020). France and Germany have recently joined the consortium.

In mid-2021 the European Union called for proposals for new research on electromagnetic fields and health, under the Horizon Europe programme. This is expected to focus on improved exposure data of the general public and specific groups considered to be at risk, whether new exposure patterns are emerging and evidence of potential biological and health effects.

The German research programme on ELF fields and health has been expanded to cover RF fields. The programme includes research on biological effects of mmWaves, exposures in 'smart cities', 5G risk perception and how to deal with misinformation. As noted above, Germany is also joining the COSMOS project. In addition, the project centre will be available for consultation by local authorities and provide an online learning platform for teachers and general practitioners.

The WHO EMF Project monograph on RF fields, to be published in the WHO Environmental Health Criteria (EHC) series, is still in progress. The WHO has commissioned 10 systematic reviews on the following key health topics, selected for their importance and/or public interest:

- cancer (observational studies)²⁴
- cancer (experimental studies)
- adverse reproductive outcomes (observational studies)
- adverse reproductive outcomes (experimental studies)
- cognitive impairment (observational studies)
- cognitive impairment (experimental studies)
- symptoms (observational studies)
- symptoms (experimental studies)
- oxidative stress
- heating.

Protocols for these reviews have been published by Environment International and are publicly available (Ijaz et al 2021), as the reviews themselves will be, probably by the end of 2022. In addition to the systematic reviews, the WHO will publish a technical report (essentially a scoping review of the scientific literature), the EHC monograph and a research agenda. The EHC will be overseen by a task group, for which a chair has already been appointed (Dr Hajo Zeeb, Professor of Epidemiology at the University of Bremen).

4.11 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

²⁴ Researchers from Auckland University are involved in this work.

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, Roosli et al 2019) consider that more recent research weighs against the existence of a cause-and-effect relationship. 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. Registry studies do not suggest any relationship, at least for periods of use up to 15 years. 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 an effect of RF fields on cancer. While a large animal study in the USA (NTP 2018b) concluded that there was 'clear evidence' of a carcinogenic effect at very high exposures, it also noted that the exposures in this study were higher than would be permitted by exposure standards. Others who have reviewed the NTP data find the results less convincing.

5 ICNIRP 2020 guidelines and limits in other jurisdictions

5.1 ICNIRP 2020 RF guidelines

ICNIRP published revised RF exposure guidelines in March 2020 (ICNIRP 2020b), after considering comments made on a draft version released in 2018 for public consultation. These replace the 1998 and 2010 guidelines for frequencies above 100 kHz.²⁵ In addition, ICNIRP published supporting material, including:

- a summary of how the newer guidelines differ from the previous guidelines
- a set of frequently asked questions
- an explanatory video.

The supporting summary highlights the main features of the 2020 guidelines but does not cover all of their features or all of their differences from the 1998 publication. These are considered in more detail in a document on the ICNIRP website.²⁶

ICNIRP's recommended exposure limits form the main part of the guidelines. Appendices cover the dosimetry behind the limits and give an overview of the health risk assessment literature on which they are based.

Overall, the basis for the guidelines is unchanged since 1998. After reviewing the literature to identify the lowest exposure levels at which adverse health effects occur, ICNIRP concluded that these effects were due to heating (and electrostimulation at frequencies below 10 MHz). It is careful to point out, however, that all potential effects were considered.

As in 1998, ICNIRP specifies both basic restrictions and reference levels. Basic restrictions are fundamental limits on quantities directly related to the physical interactions between RF fields and the body (eg, the specific absorption rate – the rate at which RF power is absorbed in the body), but a direct assessment of compliance with the basic restrictions by measurement or calculation is difficult. Reference levels are derived from the basic restrictions and expressed in terms of quantities that are more amenable to measurement or computation (eg, electric field strength or power density). Compliance with the reference levels almost always assures compliance with

²⁵ While the 2020 publication (ICNIRP 2020b) includes electrostimulation-based limits for frequencies between 100 kHz and 10 MHz, it makes no changes to the limits recommended in ICNIRP 2010, and the rationale is not restated. ICNIRP's 2010 guidelines are discussed in Section 2.1.

²⁶ www.icnirp.org/en/differences.html

the basic restrictions.²⁷ If the reference levels are exceeded, this does not necessarily mean non-compliance with the basic restrictions has occurred, but a more comprehensive evaluation in terms of the basic restrictions is needed.

The main differences between the 1998 and 2020 guidelines are that the newer guidelines:

- average whole body exposures over 30 minutes, rather than 6 minutes
- have introduced more comprehensive limits for localised exposure, which are averaged over 6 minutes
- replace the 1998 'peak exposure' limits with new limits in terms of absorbed energy for brief exposures (under 6 minutes)
- set higher reference levels at frequencies below 30 MHz that still ensure compliance with the basic restrictions (but the electrostimulation reference levels may still provide the limiting case at frequencies below 10 MHz)
- contain revised averaging times and averaging areas at frequencies over 6 GHz
- have the transition between basic restrictions in terms of SAR and power density occurring at 6 GHz, rather than 10 GHz.²⁸

In many respects and for many applications, however, there will be little difference between evaluations against the 1998 and 2020 limits. In fact, ICNIRP mentions that while it could have made small changes in some areas, it chose not to in order to maintain consistency with the 1998 limits.

Basic restrictions

As noted above, after considering research published since 1998, ICNIRP concluded that thermal effects were the most sensitive indicator of potential harm. The derivation of basic restrictions is more extensive than in 1998 and draws on non-RF research to establish thresholds at which harm might occur, particularly for localised exposures.

The 2020 guidelines introduce the concepts of:

- 'absorbed power density' as a basic restriction at frequencies above 6 GHz (1998 only used 'incident power density', the difference being that not all the incident power is absorbed: some might be reflected from the skin)
- 'absorbed energy density' for short (under 6-minute) exposures at these frequencies.

Reference levels

The ICNIRP 2020 guidelines specify reference levels for three scenarios:

²⁷ ICNIRP notes that there are rare circumstances where this might not be true, but comments that the circumstances are very unlikely to occur in practice and the amount by which the basic restrictions are exceeded is low in comparison with the reduction (safety) factors.

²⁸ This transition marks the frequency above which energy absorbed from an RF field occurs largely in the skin or shallow tissues, rather than in deeper tissues.

- whole body exposures, which are averaged 'over the whole body space' over a 30-minute period
- local exposures that are spatial peak²⁹ values averaged over a 6-minute period
- local exposures that are spatial peak²⁹ values over periods less than 6 minutes.

All three sets of reference levels must be satisfied. Table 2 shows circumstances in which each set of reference levels might be of interest.

Table 2: Circumstances in which ICNIRP (2020b) reference levels are most likely to be of interest

Reference level	Circumstances in which most likely of interest
30-minute average/whole body average	Potentially long-term exposures that do not have very high temporal peak values
6-minute average/spatial peak	Potentially long-term exposures whose intensity varies considerably across the body
<6 minutes	Exposures to sources that produce intense peaks over short periods

A broadcast transmitter that transmits at a fairly steady power would most likely be assessed against the limits for 30-minute and 6-minute average exposures. (The limits for spatial peak 6-minute average exposures are greater than the limits for whole body 30-minute average exposures.) The same would apply to cell sites. Radar sets, however, would probably also need to be compared against the under 6-minute criteria, because although the exposures might comply with the limits for 30- and 6-minute average exposures, exposures during the brief radar pulses could exceed the under 6-minute criteria.

Evaluation of exposures against the under 6-minute criteria could be complex, because the incident energy density has to be integrated over time. However, these criteria only apply at frequencies over 400 MHz.

The introduction of the spatial peak/6-minute average limits removes a long-standing problem of how to demonstrate compliance with the basic restrictions on localised SAR. In the past, this has been done in exposure standards (but not specified by ICNIRP) by allowing spatial averaging of exposures in an area around the point where the spatial peak is found. (This allows for spatial peak values that exceed the reference level.) Exposures are deemed to comply provided the spatial average is below the reference level. NZS 2772.1, for example, proposes averaging over the four corners and centre of a square, centred on the point where the spatial peak exposure is found. The size of the square depends on the frequency of the radio signal, and varies between 30 and 4.5 cm. In practice, such spatial averaging schemes are difficult to implement, especially near cell sites operating at several frequencies.

²⁹ At frequencies above 6 GHz, exposures are averaged over 4 cm²; at frequencies above 30 GHz they are averaged over 1 cm².

ICNIRP 2020 guidelines in relation to NZS 2772.1

Following its review of the ICNIRP 2020 guidelines and the way they have been incorporated into the revised Australian RF field protection standard (discussed in Section 5.2 below), the Committee considers that compliance with either of these would provide protection that is the same as or better than that offered by NZS 2772.1:1999.

5.2 Australia

ELF fields

ARPANSA recommends the use of the ICNIRP 2010 guidelines as being in line with international best practice.

RF fields

ARPANSA published revised RF exposure limits in 2021 as publication S-1 in its Radiation Protection Series (ARPANSA 2021). The limits in the standard are based closely on the ICNIRP 2020 guidelines. The standard also includes practical guidelines for its application.

5.3 European Union

Public exposures

In 1999 the Council of the EU recommended that member states adopt the 1998 ICNIRP guidelines (Council of the EU 1999). The aim was to establish an EU framework for limiting the exposure of the general public to EMF based on the best available scientific evidence. Member states were, however, free to determine what actions to take, including the application of more stringent limits.

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 2018).³⁰ 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

³⁰ This review was prepared while the United Kingdom (UK) was still part of the EU. At that time the UK recommended using the ICNIRP 1998 guidelines for managing public exposures, and legislation required compliance with the ICNIRP 1998 guidelines for occupational exposures. The requirements have not been changed since the UK left the EU.

the use of mitigation 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 other nine 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).

Occupational exposures

The EU Directive 2013/35/EU on occupational exposures to EMFs (the Directive) (which is based on the ICNIRP 2010 low-frequency guidelines, and the ICNIRP 1998 guidelines at higher frequencies) has 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.

5.4 Canada

Health Canada 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* (Health Canada 2015) (known as SC6). An accompanying document, the *Technical Guide for Interpretation and Compliance Assessment of Health Canada's Radiofrequency Exposure Guidelines* (Health Canada 2019), 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. Health

Canada commissioned the Royal Society of Canada to review and comment on SC6 before it was published (see Appendix D for a summary of the findings).

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 are set at 1.6 watts per kilogram (W/kg) for public exposures and 8 W/kg for occupational exposures,³¹ averaged over 1 gram of tissue, rather than ICNIRP's 2 and 10 W/kg, respectively, averaged over 10 grams of tissue.

The reference levels take account of dosimetry findings that under certain very particular circumstances, exposures that comply with the reference levels might not ensure compliance with the basic restrictions. For this reason, they 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. Between 48 and 300 MHz, for example, the public reference level in SC6 is 1.29 watts per square metre (W/m²), compared with 2 W/m² in ICNIRP 1998 and ICNIRP 2020.

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.

5.5 Institute of Electrical and Electronic Engineers and International Committee on Electromagnetic Safety

The 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 standards and exposure assessment standards. Anyone may apply to participate in ICES activities. Revised ELF and RF limits were published in a combined standard in 2019 (IEEE International Committee on Electromagnetic Safety 2019).

ELF fields

While the fundamental concepts behind the IEEE/ICES limits for EMF fields are very similar to the ICNIRP 2010 ELF guidelines, the guidelines differ in some significant ways. The IEEE/ICES limits (especially the reference levels, which IEEE/ICES calls 'exposure reference levels') are generally more relaxed than ICNIRP's. For example, at

³¹ SC6 uses 'uncontrolled' and 'controlled' environments, rather than 'public' and 'occupational' exposures, but the terms are largely equivalent.

50 Hz, ICNIRP recommends a reference level for the public of 200 μT , compared with the IEEE/ICES recommendation of 904 μT . 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 standard and ICNIRP also share very similar fundamental concepts in relation to radiofrequency fields. At frequencies above about 10 MHz, the reference levels for public and occupational exposures are similar, but larger differences occur at lower frequencies, with the IEEE/ICES limits generally more relaxed.

5.6 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 United States of America and published its regulations in 1996.³² 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 recent review of these limits left them unchanged, although this decision has been challenged on procedural grounds.

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 μT .

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 μT for magnetic fields and 25 kV/m for electric fields, and for RF fields it follows the IEEE/ICES occupational recommendations.

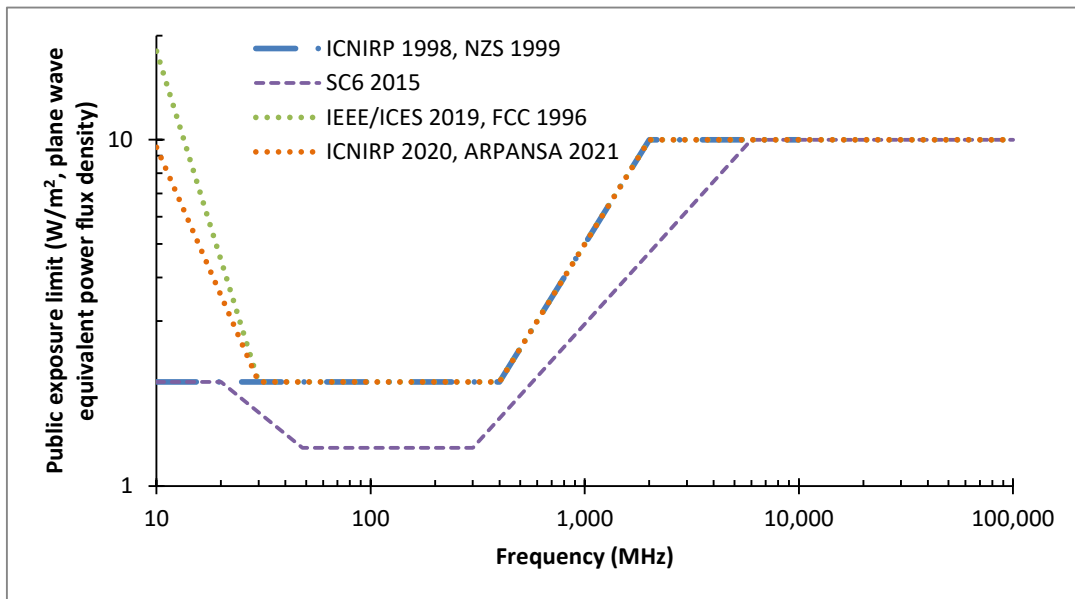
5.7 Comparison of limits for RF field exposures

Figure 2 plots the public reference levels (plane wave equivalent power flux density) recommended by ICNIRP (1998, 2020b), ARPANSA (2021), Health Canada (2015) (SC6), IEEE/ICES (2019) and the FCC for frequencies between 10 MHz and 100 GHz. If the plane wave equivalent power densities are different for the electric and magnetic fields

³² For a list of references, see www.fcc.gov/encyclopedia/radio-frequency-safety

(which may occur at frequencies below 30 MHz), the graph shows the value calculated from the electric field strength reference level.

Figure 2: RF field reference levels recommended by various organisations



Note: ARPANSA = Australian Radiation Protection and Nuclear Safety Agency; FCC = Federal Communications Commission; ICNIRP = International Commission on Non-Ionizing Radiation Protection; IEEE/ICES = Institute of Electrical and Electronic Engineers International Committee on Electromagnetic Safety; NZS = New Zealand Standard; SC6 = Health Canada (2019) exposure guidelines. Both axis scales are logarithmic.

5.8 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.

Firstly, 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'. This means 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.³³ The current review of the Resource Management Act 1991 may provide an opportunity to consider referencing the ICNIRP 2010 guidelines, which the Ministry of Health recommends using.

³³ The magnetic field reference levels in the 1998 ICNIRP guidelines were 100 μT for the public and 500 μT for occupational exposures. Electric field reference levels are the same as in ICNIRP (2010). The main reason for the change in the magnetic field reference levels between 1998 and 2010 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).

Both instruments apply only to transmission lines (and, in the case of the Transmission NPS, associated infrastructure such as substations), but not to infrastructure such as local electricity distribution networks. 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) set rules for exposures to RF fields.

Clause 55 requires network operators to take the following actions when they 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 (from both 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 NESTF references AS/NZS 2772.2:2016 in matters concerning the assessment of exposures (by calculation or measurement). A user guide is available to assist with understanding the rules and their application.

The NESTF 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 require non-network operators to follow the same rules (or, indeed, different rules) through provisions in their district plans.

Occupational exposures

The factors that distinguish occupational from public exposures are described by the Ministry of Health (2013) in this way:

People exposed occupationally are adults, exposed under controlled conditions, who should receive training to inform them of potential risks, and precautions they should be taking.

NZS 2772.1 makes a similar distinction, but adds that exposures should be 'in the course of and intrinsic to the nature of [the] work'. For people who use hand-held radios that might create exposures exceeding the public basic restriction, NZS 2772.1 also defines an 'Aware user' as someone who is aware of the potential for high exposures and measures that can be used to limit them. (Often this is just a matter of

ensuring that the radio does not transmit for more than three minutes in any six, or increasing the radio's separation from the body.)

No explicit limits on EMF exposures from personal devices (eg, hand-held radios) or equipment used in the workplace (eg, high-frequency plastic welders) are set in legislation. 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. Mobile phone network operators usually provide building owners with a handbook that details safety procedures for working around rooftop antennas, and put warning and information signs at roof access points. Electricity generating companies and Transpower have good knowledge of the location and level of high ELF fields around their equipment, and what precautions should be taken to avoid over-exposures. Awareness may be lower in other circumstances, however, such as where small employers are using high-frequency welding equipment, or staff are using high power hand-held radios for which exposures could easily exceed the public basic restriction. A similar situation is where exposures are incidental to someone's occupation, for example, someone who maintains air conditioners on a rooftop that also has antennas.

The WorkSafe website does not discuss ELF or RF field exposures directly or indirectly (eg, as part of the 'Working at height' topic) in its A to Z topics and industry pages.³⁴ It is understood that this omission is at least partly because ELF and RF fields have not (to date) been a source of serious occupational health and safety incidents in the same way that noise and vibration (topics listed in the A to Z) have been. On the other hand, the anxiety suffered by some staff who were unaware of exposures until after the event is also a health and safety concern, so it is important to delineate areas where EMF sources do – and don't – reach levels that might exceed limits, in order to avoid over-exposures, anxiety and unnecessary outages. It should also be recognised that sometimes staff need positive reassurance that a source of EMFs at or near their workplace is not a cause for worry.

The Committee does not have an answer to how this issue should be handled, but recommends that the Ministry of Health should coordinate with WorkSafe to find the best way to raise awareness. The Committee also notes that the new ARPANSA RPS S-1 RF exposure Standard (ARPANSA 2021) contains a more detailed suite of exposure categories, beyond 'public' and 'occupational', that may be worthy of consideration.

³⁴ www.worksafe.govt.nz/topic-and-industry/

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 1993. 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 require suppliers to maintain this information in a compliance folder. 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 lower than 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). Therefore reported SAR values should generally be taken as indicating whether 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

4G (also known as long-term evolution - LTE) services have been available in New Zealand for about 10 years. 4G makes more efficient use of the radio spectrum than previous technologies, 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 so the exposures they produce) to be just sufficient to maintain the link. The efficiency of power control in 3G and 4G phones and devices is well established, and transmit powers during a voice call are typically 100 times lower than the maximum possible.

Independent monitoring commissioned by all three New Zealand operators has found that exposures in public areas near cellsites 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

5G is discussed in detail in Section 4.9.

Small cells

'Small cell' is an umbrella term that covers low-power cellsites intended to cover limited areas. Depending on the intended coverage range, small cells have also been referred to as femto-, pico- and micro-cells. They can be used to improve coverage and capacity in places like shopping malls, the central business district and other areas with high population density. Small cells are also physically small, with dimensions of the order of 30 to 40 cm. In some places they may be incorporated into other pieces of 'street furniture' such as bus stops.

While small cells are not new, their numbers are likely to increase as 5G deployment expands. In the 2020 early allocation of spectrum for 5G in the 3.5 GHz band, 40 MHz was allocated to Dense Air, a company that specialises in small cell deployments and already has spectrum in the 2,600 MHz band. The company works with existing carriers to improve capacity and coverage.

Because of their low power, exposures near small cells are also low, even though they may be mounted closer to the ground than sites intended to cover larger areas. This has been confirmed by measurements in South Africa (van Wyk et al 2019), Australia (ACMA 2020) and New Zealand. The improved coverage also means that mobile phones can transmit at lower power than they would otherwise do, thereby reducing exposures to the user.

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. During 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: These 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 500th) 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.³⁵

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 between 36 seconds and 7 minutes per hour (and were silent for 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 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

³⁵ Some devices may also issue 'probe' signals to find nearby access points.

workplace. Massardier-Pilonchery et al (2019) reported on measurements in seven public libraries in France, and found that the mean exposure due to WiFi was 0.00002% of the NZS 2772.1 public limit and much lower than exposures from other sources.

A recent review concluded that there are no detrimental health effects from WiFi exposures below regulatory limits (Dongus et al 2021).

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 example, for a vehicle charging system that transfers several kW of power with a source-load separation of up to 30 cm,³⁶ 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 are data intensive, others (eg, control of street lamps, reading water meters) 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

³⁶ Vehicle charging systems have the supply coils just under the ground surface, and the receiver coils beneath the vehicle.

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.

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 of Health 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. National and international reviews of the research are also key sources of information to support policy development.

In 2019 the Ministry signed a Memorandum of Understanding (MoU) with ARPANSA to exchange technical information and cooperate in the area of non-ionising radiation. Among other things, the MoU envisages sharing guidelines and standards for non-ionising radiation protection.

The Ministry has several pages on its website to provide EMF information.³⁷ 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.³⁸ These pages are updated as new reports and information become available. In addition, the Ministry has supported the publication of commentaries intended for the New Zealand medical profession (Elwood 2020; Elwood and Wood 2019a, 2019b).

The Ministry does not fund or commission EMF research. Funding is the responsibility of the Health Research Council, which has provided money for the New Zealand arm of the international MOBI-Kids study (see Section 6.4).³⁹ 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).

³⁷ See the links from www.health.govt.nz/our-work/radiation-safety/non-ionising-radiation

³⁸ See www.health.govt.nz/our-work/radiation-safety/non-ionising-radiation/research-non-ionising-radiation

³⁹ Funding for MOBI-Kids in New Zealand was also provided by Cure Kids.

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 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 currently it 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.

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, see the WHO website: www.who.int/initiatives/the-international-emf-project

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. Its 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 G. 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.

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 and the participation of ARPANSA staff (particularly since the inception of the ARPANSA electromagnetic energy programme) are especially valuable in this respect. The Committee does not, however,

aim to conduct a systematic review of all recently published research, as this work is already undertaken periodically by expert panels assembled by national and international health and scientific agencies. These reviews are an important input to the Committee's work.

While there is sometimes public concern over the presence of industry representatives on the Committee, in practice these representatives 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 coordinated the New Zealand arm of the MOBI-Kids study. As discussed in Section 4.4, 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 findings were published in late 2021.

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.

New Zealand research on neurodegenerative diseases

The Massey University Centre for Public Health Research has also undertaken research on neurodegenerative diseases in relation to ELF fields, electric shocks and job titles. One study (G Chen et al 2019) looked at associations between occupations and motor neurone disease and found the disease was associated, albeit with wide confidence intervals, with electricians and telecommunications technicians (among several other occupations). A second study (G Chen et al 2021) found support for an association between electric shocks, but not ELF magnetic fields, and motor neurone disease.

6.5 EMF monitoring in New Zealand

ELF fields

Some ELF field monitoring may be required as a condition attached to a designation or resource consent for the construction or modification of electrical infrastructure. The results of such monitoring would normally be forwarded to the consenting authority. The Transpower North of Auckland and Northland project completed in 2014, for example, which traversed several local authorities, required measurements at several points along the length of the project.

In addition, Transpower and some lines companies may voluntarily arrange for measurements to be made in response to landowner queries about existing infrastructure, or proposed upgrades.

The Ministry of Health booklet *Electric and Magnetic Fields and Your Health* (Ministry of Health 2013) and Transpower information sheets provide information on typical levels in various settings.⁴⁰

RF fields

As noted in Section 6.1, when a network operator establishes a telecommunications facility at which exposures in publicly accessible areas are expected to exceed 25% of the public limit in NZS 2772.1, the NESTF requires the operator to submit a report confirming that exposures comply with the public limit to the local authority once the site is operational.

Some cellular network operators commission independent measurements around their sites, and results from those surveys are made available on the Ministry of Health website.⁴¹ Cellular network operators may also undertake measurements for individuals or organisations such as schools that express interest or concern about nearby sites.

⁴⁰ www.transpower.co.nz/safety/keep-safe/electric-and-magnetic-fields

⁴¹ www.health.govt.nz/our-work/environmental-health/non-ionising-radiation/independent-cellsite-monitoring

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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 23 years old, ICNIRP confirmed in 2020 that the limits on which it is based remain protective for current commercial applications of RF technology. 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.

The underlying science behind the exposure limits in NZS 2772.1 has not changed since it was published.

‘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 35 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-ionizing 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).

‘ICNIRP is dominated by industry interests’

The ICNIRP statutes (available on the ICNIRP website) require that ‘No member of the Commission shall hold a position of employment that in the opinion of the Commission will compromise its scientific independence.’ The website also notes that

ICNIRP members cannot be employed by industry. All members of ICNIRP have to complete a declaration of interests and these are also available on the ICNIRP website.

ICNIRP's funding comes from national and international public bodies, and is reported annually.

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 (121 agents as at September 2021)	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 (89 as at September 2021)	Positive associations for which a causal interpretation is credible, but could also be due to chance, bias or confounding.	Causal relationship established in two or more species, or two or more independent studies in a single species.	Polychlorinated biphenyls (PCBs) Fumes from hot frying Red meat
2B	Possibly carcinogenic (319 as at September 2021)	Either: 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 or: 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 two or more species, or two or more independent studies in a single species.	Pickled vegetables (traditional in Asia) Petrol engine exhaust ELF magnetic fields RF fields
3	Not classifiable (500 as at September 2021)	Evidence has weaknesses that mean no conclusions can be drawn.	Either the data suggests a carcinogenic effect but is too limited to make a definitive evaluation, or 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, 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)

Note: This table summarises the scheme at the time that ELF and RF fields were evaluated. A revised approach that applies the principles of systematic review, makes the role of mechanistic studies more explicit and removes Class 4 was adopted in 2019 (IARC 2019a).

Appendix C: Recent ELF reviews

Reviews marked with an asterisk* have been added since the Committee's previous (2018) *Report to Ministers*.

Date	Group and publication date	Mandate, area covered and method	Conclusions
April 2021	SSM (Swedish Radiation Safety Authority) Scientific Council on Electromagnetic Fields (2021, April)*	See description for SSM (2013, March) review below.	<p>Whether there is a causal link between magnetic field exposure and childhood leukaemia is still unresolved. A newly developed mouse model should be used in future in vivo studies investigating this. Studies on ELF magnetic fields, electric shocks and neurodegenerative diseases continue to give mixed results.</p> <p>Recent in vitro studies have investigated several end points and generally show no effects.</p>
March 2020	SSM Scientific Council on Electromagnetic Fields (2020, March)*	See description for SSM (2013, March) review below.	<p>No new studies on childhood leukaemia have been published, and the previous conclusion was that epidemiological associations have been observed but a causal relationship has not been established.</p> <p>Animal studies provided various and partly contradictory effects, but provided no insights on interaction mechanisms. Increasing numbers of studies looking at cytokines as an end point might be indirectly relevant to effects on childhood leukaemia.</p> <p>In vitro studies do not show induction of genotoxic and epigenetic effects, but oxidative stress is slightly induced.</p>
April 2019	Expert working group set up by the French Agency for Food, Environmental and Occupational Health & Safety (ANSES 2019, April)*	<p>Updates previous opinion published in 2010.</p> <p>Review undertaken by a working group with expertise in exposure measurement, epidemiology, medicine, biology, physiology and EMF regulations. Conducted according to French standard for expert appraisals. Working group drew on the results of previous assessments and a systematic analysis of studies published since 2010, concentrating on childhood leukaemia, other forms of cancer and neurodegenerative diseases.</p>	<p>It is possible ELF fields have an effect on childhood leukaemia, based on limited epidemiological evidence. The data does not allow conclusions to be drawn on other types of childhood or adult cancers.</p> <p>While some studies suggest a link between ELF fields and ALS, interpretation is difficult and the link could be explained by other factors. Meta-analyses highlighted a link but publication bias makes this unreliable. Further research is recommended. Studies on other neurodegenerative diseases have heterogeneous results and do not allow conclusions to be drawn. Some experimental studies suggest a possible effect of weak fields on the EEG, similar to that found for RF fields.</p> <p>ANSES recommendations included avoiding any increase in the numbers of people exposed near very high voltage lines, and not allowing new sensitive facilities where exposures might exceed 1 μT. There were also recommendations for continuing research.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
May 2019	SSM Scientific Council on Electromagnetic Fields (2019, May)*	See description for SSM (2013, March) review below.	<p>New studies on ELF fields and childhood leukaemia reported no consistent associations, but have the same limitations as previous studies. The conclusion that epidemiological studies observe associations but no causal relationship has been established still holds. A new analysis looking at risks as a function of time period for which they were reported found no obvious changes over time.</p> <p>Occupational studies on adult cancers are inconsistent. A large French study found no associations between ELF exposures and pregnancy outcomes.</p> <p>New studies on ALS suggest an association with ELF fields, but the role of electric shocks is unclear. A meta-analysis found that studies with better ELF field assessment were more likely to find increased risks. A meta-analysis of studies on Alzheimer's disease found an overall increased risk but considerable heterogeneity between studies.</p> <p>A new animal study found no effects of ELF fields on cancer, but no animal studies have directly addressed childhood leukaemia. Cellular studies looked at several end points but results are inconsistent.</p>
May 2018	SSM Scientific Council on Electromagnetic Fields (2018, May)	See description for SSM (2013, 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>Epidemiological 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 on 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>Leukaemia risk in children with an average exposure $>0.3\text{--}0.4 \mu\text{T}$ 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 $>0.4 \mu\text{T}$. 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 of the 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. 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)	<p>See description for SSM (2013, March) review below.</p> <p>This review also gives an overview of how the research evidence had changed over the 13 years that SSM had produced these reports.</p>	<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 question of an ELF field – childhood leukaemia association. In contrast to the 2015 conclusions, a large Swedish study suggested that magnetic fields are not associated with ALS.</p>
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 (2013, March) review below.	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

Date	Group and publication date	Mandate, area covered and method	Conclusions
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.</p> <p>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>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 another risk factor is 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 2014	SSM Scientific Council on Electromagnetic Fields (2014, March)	See description for SSM (2013, March) review below.	<p>No convincing evidence of a link between ELF exposures and self-reported symptoms.</p> <p>Results from new epidemiological studies are 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> <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.⁴²</p> <p>The results of in vivo studies are not very consistent and need replication. These should address the childhood leukaemia question.</p>

⁴² 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
May 2014	Biological Effects Policy Advisory Group of the Institution of Engineering and Technology (2014, May)	Updates 2012 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>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> <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 reporting effects that subsequent studies are unable to replicate suggests that better quality control should be applied before publication.</p>
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 were assessed to determine the weight they should be given in overall assessment; evidence from different types of research (eg, epidemiological, 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 has 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)	Project funded by the European Commission. The Network includes participants from universities and research centres in seven	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

Date	Group and publication date	Mandate, area covered and method	Conclusions
		<p>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>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>
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 RF fields.</p>	<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

Reviews marked with an asterisk* have been added since the Committee's previous (2018) *Report to Ministers*.

Date	Group and publication date	Mandate, area covered and method	Conclusions
February 2022	Expert working group set up by the French Agency for Food, Environmental and Occupational Health & Safety (ANSES 2022, February)*	Reviews studies on health effects of exposures to RF fields in the 700–2,100 MHz, 3.5 GHz and 26 GHz frequency bands. Review carried out by expert group and conducted according to French standard for expert appraisals. For the 700–2,100 MHz frequencies, the review relied on previous ANSES appraisals in these frequency bands.	Exposures in the 700–2,100 MHz bands are likely to be similar to those from existing mobile phone systems. Recent expert reports do not show that health effects occur at these frequencies. Exposures from 3.5 GHz 5G are likely to be similar to those from existing mobile phone systems. Few studies have been undertaken at 3.5 GHz. There is some uncertainty extrapolating from research undertaken at lower frequencies but it is considered unlikely that 5G in the 3.5 GHz band presents a new health risk. Exposures at 5G from sites and devices at 26 GHz are likely to be low. There is insufficient data to determine whether exposures at these frequencies might cause health effects. The group also made research recommendations.
April 2021	SSM (Swedish Radiation Safety Authority) Scientific Council on Electromagnetic Fields (2021, April)*	See description for SSM (2013, March) review below.	Most new research on mobile phones and brain tumours suggests an absence of risk. Several studies suggest that associations between mobile phone use and non-specific symptoms are mediated by factors such as insufficient sleep or stress. The COSMOS study found no association between mobile phone use and tinnitus or hearing loss. Weak associations with headaches are unlikely to be due to RF fields. RF exposure does not change the concentration of biomarkers in EHS subjects, but small sample sizes limit the statistical power to prove absence of risk. There were inconsistent findings from studies on brain activity, and Universal Mobile Telecommunications System (UMTS) exposure had no effects on sleep parameters. In vivo studies again gave inconsistent results, but increased oxidative stress and effects on behaviour and spermatozoa (with no effect on fertility) continue to be found. In vitro studies generally show no effects.
September 2020	Standing Committee on Electromagnetic Fields of the Health Council of the Netherlands (2020, September)*	Provides an overview and assessment of the national and international studies published on the possible health risks of 5G, to supplement previous advisory reports in this area. Assesses the extent to which current public	Relationships between exposure to radiofrequency electromagnetic fields and the occurrence of cancer, reduced male fertility, poorer pregnancy outcomes and congenital defects were classified as 'possible'. However,

Date	Group and publication date	Mandate, area covered and method	Conclusions
		<p>health standards in this area are based on the latest scientific understandings.</p> <p>Used draft review by WHO and SSM reports as basis, supplemented by literature searches. Divided into three frequency ranges: 700–2,200 MHz, 2,200–5,000 MHz, >5 GHz. Studies assessed for quality. Overall assessment considers whether RF fields have the potential to cause effects (hazard evaluation, rather than risk evaluation) for various health outcomes (eg cancer, male fertility, symptoms) and biological processes (eg behaviour, sleep, immune system).</p>	<p>the committee considers the relationship between exposure and these and other diseases or conditions is neither proven nor probable.</p> <p>It is probable that changes in electrical activity in the brain are associated with exposure to radiofrequency electromagnetic fields, but it is not known whether that is favourable or unfavourable in health terms. Where changes occur in the majority of other biological processes, it neither has been demonstrated nor is probable that these are associated with exposure to radiofrequency electromagnetic fields.</p> <p>The committee saw no reason to stop using lower-frequency bands for 5G, but recommended exposure monitoring. It recommended undertaking further research on frequencies around 26 GHz, and that these frequencies should not be used for 5G until the results of that research are available. The ICNIRP 2020 guidelines should be used as the basis for policy in the Netherlands, and exposures should be minimised as much as that is reasonably achievable.</p>
March 2020	SSM Scientific Council on Electromagnetic Fields (2020, March)*	See description for SSM (2013, March) review below.	<p>Cancer incidence time trends do not suggest any increase associated with cellphone use. They do suggest, however, that some changes could be related to diagnostic practices. A study on mobile phone use and survival of glioma patients found no effect on survival time.</p> <p>Studies on mobile phone and other device use and outcomes such as cognitive function and behaviour often report associations, but some suggest factors other than RF fields are the causal factor. Separating RF exposure from other aspects of mobile phone use is challenging. Recent human experimental studies support the conclusion that exposures to RF fields have no adverse short-term effects.</p> <p>Animal studies on effects on the brain and behaviour gave inconsistent results. Other studies reported effects on oxidative stress on some organs but not others. A systematic review is needed in order to draw any conclusions about possible health implications. Most in vitro studies report no effects of RF exposures, except when exposures were high.</p>
February 2020	US Food and Drug Administration (2020, February)*	<p>Considers the evidence on whether exposures to RF fields from 100 kHz – 6 GHz affect cancer formation. Reviews peer-reviewed epidemiological and in vivo studies published between 1 January 2008 and 1 August 2019, plus the final reports of the NTP study published in November 2018. Review carried out by FDA staff and peer-reviewed by scientists in relevant disciplines. Papers reviewed sourced through searches of Medline and EMF</p>	<p>There is insufficient evidence to support a causal association between RF radiation exposure and tumorigenesis. There is a lack of clear dose–response relationship, a lack of consistent findings or specificity and a lack of biological mechanistic plausibility. Existing epidemiological evidence indicates that if any risk does exist, it is extremely low compared with both the natural incidence of the disease and known controllable risk factors.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
May 2019	SSM Scientific Council on Electromagnetic Fields (2019, May)*	See description for SSM (2013, March) review below.	<p>Several new meta-analyses on cellphone use and brain tumours analyse the same study base and do not help understanding. Overall, brain tumours show no changes in incidence over time.</p> <p>The NTP and Falcioni studies have many good aspects, including large sample size. Results on heart schwannomas are inconsistent between the two studies. Heart schwannomas are rare in humans, and these are the first animal studies to find them. It is peculiar that the condition shows up in rats but not in mice. These studies are not clear indicators of a cancer risk in humans.</p> <p>Animal studies of behavioural and cognitive effects found no dose–response relationship. Eight out of nine studies found an effect of RF fields on oxidative stress.</p> <p>50% of the cellular studies could not be considered because of their poor quality. Most of the studies that were considered show no effects of RF exposure, but confirm that RF can modify the effects of chemical or physical agents.</p>
May 2018	SSM Scientific Council on Electromagnetic Fields (2018, May)	See description for SSM (2013, 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 considering them, 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"> • attempt to understand complexities of EHS and characterise it • examine the plausibility of various assumptions made to explain the causes of the reported disorders. <p>Also looks at ELF fields as a potential cause.</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>

Date	Group and publication date	Mandate, area covered and method	Conclusions
		<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>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. The expert group recommended a wide range of further research.</p>
July 2016	Biological Effects Policy Advisory Group of the Institution of Engineering and Technology (2016, July)	<p>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>	<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 both for 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	Electromagnetic Fields Committee of the Health Council of the Netherlands (2016, June)	<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>
June 2016	Expert working group set up by the French Agency for Food,	Objectives included to:	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

Date	Group and publication date	Mandate, area covered and method	Conclusions
	Environmental and Occupational Health & Safety (ANSES 2016, June)	<ul style="list-style-type: none"> • produce an inventory of radio products intended for under six-year-olds and assess the exposures from them • review current regulations covering RF exposures of children • analyse the research on RF and health, especially related to children's health • assess potential health risks to children from RF exposures from devices intended for them. <p>Methodology was the same as that adopted in the ANSES (2013) review of health effects of RF fields – see below.</p>	<p>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>Effects on cognitive functions and wellbeing are possible, 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 requiring SAR tests of products such as tablets and toys. These should be made under actual conditions of use and the results 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.</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"> • 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 • making no changes to existing French exposure limits.
May 2016	SSM Scientific Council on Electromagnetic Fields (2016, May)	<p>See description for SSM (2013, March) review below.</p> <p>This review also gives an overview of how the research evidence had changed over the 13 years that SSM had produced these reports.</p>	<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 they were not entirely consistent with previous studies. Generally no effects have been found on cognitive</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
			<p>performance, nor 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>
March 2015	SSM Scientific Council on Electromagnetic Fields (2015, March)	See description for SSM (2013, 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. Recent epidemiological 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, use of 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.</p> <p>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, epidemiological 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>

Date	Group and publication date	Mandate, area covered and method	Conclusions
			<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>
September 2014	Electromagnetic Fields Committee of the Health Council of the Netherlands (2014, September)	<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%) reports 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).</p> <p>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 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>
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"> • 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) • recommend whether a formal review of RPS3 should be undertaken • prepare an independent assessment of the RF research literature for publication. <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</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</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
		ARPANSA review of epidemiological and human provocation research.	<p>resonant conditions may produce higher temperature rises than previously thought, and the acceptability of this should be reviewed.</p> <p>Epidemiological 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>
March 2014	SSM Scientific Council on Electromagnetic Fields (2014, March)	See description for SSM (2013, March) review below.	<p>Most in vitro studies do not support an effect of RF on DNA damage or cell death, and indicate 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' evidence⁴³ 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"> • 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 • making no changes to existing French exposure limits.
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, epidemiological, in vivo and in vitro studies) is integrated in the final stage of the evaluation. Epidemiological 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>

⁴³ 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
- does not exist.

Date	Group and publication date	Mandate, area covered and method	Conclusions
June 2013	Electromagnetic Fields Committee of the Health Council of the Netherlands (2013, June)	<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>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 placebo effect.</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 and organisations, including WHO.</p> <p>Builds on previous European-funded collaborations investigating and collating the results of EMF research. 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 EHS has 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).</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>A large number of studies examining the possible effects of weak RF fields has been carried out and provides no evidence of adverse health effects. Some measurable biological or physiological effects cannot be ruled out.</p>

Date	Group and publication date	Mandate, area covered and method	Conclusions
		<p>Focused on research investigating possible health effects of weak fields (defined as fields below ICNIRP reference levels).</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 provides 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>
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 has 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>
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>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>

Date	Group and publication date	Mandate, area covered and method	Conclusions
		<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 the former are more directly relevant to human health.</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>Some evidence indicates 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 (2007) was first published in 2007 and was partially updated in 2012, 2014 and 2017. (Summaries of research papers and abstracts updated to 2020 are available, but there is no attempt to review the quality of the work.) 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 that undermine its credibility (AFSSET 2009; COMAR 2009; EMF-NET 2007; Grimes and Bishop 2017; 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 number of studies showing effects or no effects (65% and 35% respectively for RF fields). It includes a brief uncritical discussion of the findings but does not attempt to explain apparently contradictory results or discuss the strengths and weaknesses of the individual studies.

Before listing abstracts, the section makes this comment:

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 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 (Health Council of the Netherlands 2012) 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 of studies 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 is covered in several sections (eg, the original Sections 8 and 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 (2011),⁴⁴ Eskander et al (2012), Heinrich et al (2010), Thomas et al (2008, 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 BioInitiative Report does not mention several other relevant studies on the effects of exposures to RF fields from cellsites, 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).

⁴⁴ Cited as 2012 in Section 24, but correctly listed in the references as 2011.

Appendix F: Assessment of scientific research

A very large number of papers investigating possible health effects of EMFs has been published. The EMF-Portal, an online database of EMF studies maintained by the RWTH Aachen University,⁴⁵ had almost 35,000 entries at the end of 2021. The way that such a large body of scientific research is brought together to try to build up a picture of how some agent might affect health is not always well understood. This appendix presents some issues that are considered in health effects assessments and outlines some complexities and pitfalls that can arise in these assessments. Although the focus here is on electromagnetic fields, the approaches described are commonly used to assess potential health risks of any agent. For a more detailed discussion of these issues, see, for example, Roosli (2014) and Wood and Karipidis (2017).

It is not possible to prove anything is absolutely safe, if ‘absolutely safe’ means no possibility of harm to anyone. No matter how many scientific studies and observations produce no evidence of health effects associated with an exposure, it will still always be possible to conceive of circumstances where harm might occur. For example, harm might occur because of unusually high exposures or because of the (theoretical) possibility that some individuals are extraordinarily sensitive to the exposure.

Much of modern society wants to experience the benefits of new technologies, and many of these technologies entail new exposures for which we can have no assurance of absolute safety. In the end, society has to decide whether particular technologies and their associated exposures are acceptable.⁴⁶ It is not up to scientists alone to make the risk–benefit judgements. Where scientists can help is in supplying the most comprehensive information possible to permit such judgements to be reached.

Only rarely do studies of any one form of exposure produce uniformly reassuring results in a wide range of different types of test. More typically, some tests show no evidence of harm, whereas others of a different type suggest that adverse effects are indeed possible. It is important that knowledgeable and experienced people assess all the studies, try to resolve the discrepancies, and – if discrepancies cannot be resolved – use their judgement and experience to decide on how much weight should be given to conflicting results. They should also explain the reasoning behind their conclusions.

Assessing risks always means assessing **all** the available evidence, not just the studies that appear to show either harmful or beneficial effects.

All judgements (of risk or otherwise) involve a degree of subjectivity. Experts may reach different conclusions using the same or similar data. While this may look like serious

⁴⁵ www.emf-portal.org/en

⁴⁶ This is not a new consideration. Many new technologies have been accepted in the past that clearly present health risks. What has changed is that today we are more aware of the potential for risk and it is easier to share opposing (and sometimes polarising) points of view.

scientific controversy, the actual disagreement may be less so. In addition, when such conclusions are presented in the media or on social media, the differences may be accentuated and the public may not get a clear sense of where the consensus scientific opinion lies or of the nature of the relative strengths and weaknesses of the data supporting the different conclusions.

Three broad categories of scientific study can contribute to resolving the scientific debate over exposure to electromagnetic fields. Two (in vitro and in vivo laboratory studies) are based on experimental work and the third (epidemiological study of human beings) is based on systematic observation of human populations. All three have value in the assessment of health risk, and all three have their advantages and disadvantages. Particular advantages and disadvantages of the three categories of study, and factors affecting their reliability, are briefly described below.

Laboratory (experimental) studies

In vitro studies

In vitro (Latin, 'in glass') studies take place in the laboratory, outside the body of an organism. Tissue culture studies are an example. In vitro studies are usually relatively easy to carry out and inexpensive. However, they are limited in the range of effects that they can demonstrate and they have the serious disadvantage that they do not take into account the complex and dynamic processes that occur in complete organisms (including, of course, human beings). Thus, they cannot demonstrate effects that would occur in whole organisms, although they may well suggest some possible effects. Such suggestions need to be followed up with studies using whole animals or with epidemiological studies.

In vitro studies are probably most useful for supporting or investigating possible mechanisms of effects that may be suggested by in vivo laboratory or epidemiological studies. In themselves, however, they do not provide definitive evidence of health effects.

In vivo studies

In vivo (Latin, 'in a living thing') studies, also conducted in the laboratory, involve experiments with whole animals, such as rats or mice. These studies are more complex and expensive than in vitro studies and their results are more appropriate for predicting effects on humans. Generally, they involve groups of animals subjected to different degrees of exposure to electromagnetic fields, while all other factors are held constant.

A particular advantage of in vivo studies is that the degree of exposure of the animals can be controlled and measured very precisely. A disadvantage of these studies is that the animal species (often rats and mice) frequently differ from humans in their response to exposures. Also, to have a possibility of demonstrating any effects, the experimental levels of exposure often need to be much higher than humans would be

likely to be exposed to. This is because the number of animals that can be included in any one study is usually limited to a few hundred. However, millions of humans may be exposed (perhaps at much lower levels). If only a small percentage of those millions of humans is actually affected by the exposure, that would still be a large number of people, but this same small percentage would be difficult to detect with any degree of statistical confidence using only a few hundred animals. Thus, to compensate for the relatively small number of animals and to increase the chances of detecting any effect, high exposure levels are used.

Even if effects are detected in such a study, careful consideration must be given to the possibility that those effects are solely a result of the high exposures. At the lower exposure levels to which humans are subject, the body's protective mechanisms may prevent any harm from occurring. We know, for example, that all chemicals (including water and oxygen) are poisonous or otherwise harmful, even fatal, in some circumstances or at some levels of exposure. However, the levels of these chemicals to which humans are generally exposed do not have harmful consequences for most people.

A further limitation of *in vivo* studies is that they are rarely useful for investigating the possibility of interactions (either protective or harmful) between the multiple exposures that humans are subject to in everyday life. Because of the vast number of different exposure combinations that are possible, it is not feasible to test all (or even a fraction) of these in animal studies.

Study quality

The fact that a study has been peer-reviewed before publication is, unfortunately, not a guarantee of unimpeachable quality. The Swedish Radiation Safety Authority (eg, SSM Scientific Council on Electromagnetic Fields 2019, 2020) and Vijayalaxmi and Prihoda (2018) found numerous studies that had no sham-exposed controls or positive controls.⁴⁷ Vijayalaxmi and Prihoda (2018) also noted that many analyses of exposed cells or animals were not blinded.⁴⁸ Another common problem is that the exposure system is either poorly described or poorly conceived, or both, with the result that the exposure conditions – or whether there was any exposure at all – are not known.

⁴⁷ A **sham control** is an experimental animal or cell culture that is treated in exactly the same way as those exposed to EMFs, but does not receive the exposure. A **positive control** is an experimental animal or cell culture deliberately exposed to an agent known to produce the effect being investigated, in order to confirm that the experiment is capable of detecting it and provide some comparative measure of the size of the effect.

⁴⁸ **Blinding** means that the person examining the experimental cells or animals does not know whether they were exposed or not. In this way, this approach removes the potential for conscious or unconscious bias in the analysis.

Epidemiological (observational) studies

Epidemiological studies take place outside the laboratory, in the world at large. Occupational and environmental epidemiological studies investigate the relationships between exposures and health outcomes in populations of people. They study human health by observing human beings – whereas laboratory studies may involve use of other animals or of tissues and cells. Epidemiological studies involve levels of EMFs to which humans are actually exposed and exposure periods of up to several years.

Exposures

Apart from the appropriateness of species and EMF exposure levels, epidemiological studies of EMFs differ from laboratory (in vitro or in vivo) studies in another key way.

Laboratory studies are carried out in highly controlled environments, where it is possible to exactly control the circumstances of the experiment, including all other exposures. Usually, only one exposure is allowed to vary at any one time. In contrast, environmental epidemiological studies into health effects from exposures to EMFs cannot usually control exposures. As well, every person is subject to their own individual set of exposures (what they eat, how much exercise they take, substances they may be exposed to at home or in the workplace), many of which may not be measurable with any degree of certainty.

Occupational and environmental epidemiological studies are **observational**, because they do not involve control of the real-world circumstances of exposure. Exposure levels can only be observed and estimated. In an **experimental** situation, every effort is made to control and precisely measure exposures but this is a potential weakness as most non-infectious diseases, including cancers, may be influenced by a range of different exposures or combinations of such exposures. These exposures, or their combinations, may be protective or harmful.

Confounding

In the real world, exposures are often associated with one another. This leads to the problem of **confounding**. Confounding occurs when exposures to several factors are associated, and when at least some of them are causal factors for the disease. Multiple exposures can result in non-causal exposures appearing to be associated with the disease, if they are correlated with actual causal exposures. For example, cigarette smokers have often been shown to be more likely than non-smokers to be coffee drinkers. Unless smoking behaviour were taken into account, coffee drinking might appear in epidemiological studies to be a cause of lung cancer and the numerous other diseases associated with smoking cigarettes.

For radiofrequency fields, confounding might arise, for example, if a population around the site of a transmitter such as a television tower were of a different socioeconomic group to the comparison population. Because many cancer risks are related to

socioeconomic factors, the population around the television tower might appear to have a higher cancer rate if the data analysis did not take the socioeconomic factors properly into account.

Bias

Confounding is one form of bias that may occur in an observational study. Many other forms of bias may occur and can be generally grouped into categories of selection and information biases.

Selection bias occurs when those people in a study are different to those not in a study. For example, if a cluster of cancers occurs (as will certainly happen from time to time, purely by chance) then this can draw attention to itself and create the impression that there is a common underlying cause, whereas that may not be the case.

The other major form of bias in observational studies is **information bias**. This involves misclassification of the degree of exposure of people in the study or misclassification of their disease status. Such bias can cause quite misleading results in epidemiological studies, either by making non-existent effects appear to be happening or by obscuring the presence of actual effects. All epidemiological studies need to be examined for the possibility of bias before their results are accepted at face value, and the possibility that bias may exist must always be kept in mind.

The ecological fallacy

The best epidemiological studies measure exposures of each individual in the study. Some studies, however, compare groups of people whose exposure is not measured but instead is inferred from some other characteristic, such as where they live. These are ecological studies. These may be useful for indicating further avenues for research, but it is generally recognised that an association observed in an ecological study should not be assumed to show a cause-and-effect relationship. This error is so well recognised that it is referred to as the **ecological fallacy**.

One example is that many ecological studies showed relationships between heart disease in different areas and various characteristics of drinking water. This initiated much research, none of which showed an important relationship at the individual level. The explanation is that areas that differ in their water supplies also differ in many other ways that are more directly related to heart disease.

Other factors affecting reliability of research findings

Some factors affecting the reliability of the findings of laboratory research and observational studies (and so the weight that can be given to those studies when reviewing the research as a whole) have already been discussed. Some additional factors to consider are applicable to both types of work.

Statistical tests and multiple comparisons

It is important to distinguish between results that represent a real effect due to exposure and results that are simply due to chance or random variation in the biological system or population being studied. The effects of chance are always a possibility when the study population or the number of observed effects is small. Statistical tests have been developed to investigate the likelihood that chance may be an important factor. It is important to apply the correct tests.

However, when many statistical tests are carried out, as they commonly are in an investigation of whether a wide range of diseases or experimental outcomes is associated with a particular exposure, then it is likely that, just by chance, some of these tests will produce statistically significant results. This is known as the problem of multiple comparisons. Elwood and Wood (2019a) point out, for example, that the analysis of the NTP studies exposing rats and mice to RF fields involved over 1,000 comparisons, which would result in many apparently positive findings arising through chance alone.⁴⁹ Moreover, in epidemiological studies, even highly statistically significant results may be caused by bias or confounding, and such possibilities need to be thoroughly investigated.

Replicability and consistency of results

A key consideration in assessing the results of *in vitro* and *in vivo* studies is whether the experimental results can be replicated in other laboratories by other investigators. Other investigators using exactly the same material and exactly the same methods ought to be able to come up with exactly the same results. If they cannot, it is likely that other – unidentified – factors have affected the experiment's results. In that case, the results of the original experiment cannot be assumed to apply anywhere else.

As with *in vitro* studies, it is important that *in vivo* results are replicable, including with other animal species and strains. A result that is obtained for more than one species and more than one strain of a particular species is more likely to have wider relevance, including relevance to humans.

The analogue of replicability in epidemiological studies is consistency. If epidemiological studies are subject to the possibility of chance variation and bias, then similar results obtained by different studies with different populations make such influences less likely to explain the results. Nevertheless, it is still possible for the same sort of bias to be present in a range of different studies and consistency of the results of several studies does not, of itself, provide complete assurance that bias is not a factor.

Care must also be exercised in judging consistency. For example, it is not enough to conclude that, because the rate of one form of cancer is increased in one study and the rate of another form of cancer is increased in another study, the two studies are consistent. All cancer types are different and have different causes. Even within one category of cancers, such as leukaemias, types vary significantly. An increased rate of

⁴⁹ Elwood and Wood also note, 'The focus of the NTP methods is to identify possible harmful agents, while accepting frequent false positives, on the basis that the findings will be checked by further research.'

one type of leukaemia would not necessarily be consistent with an elevated rate of a different type of leukaemia in another study. Adult leukaemias are also likely to have different causes from childhood leukaemia. In other words, it is not enough to avoid comparing apples and oranges. You must also be sure that you are not comparing Granny Smiths with Golden Delicious.

Integrating the data

The overall assessment of likely health risk associated with an exposure is complex, involving integration and synthesis of all relevant information into a coherent picture. Overall assessments by different scientists may not agree completely, or even partially, but differences can often be resolved with reasoned discussion. Ultimately, it is the quality of the science that is important, rather than the number of scientists subscribing to a particular view.

In general, if good epidemiological data exists, it should take precedence over the results of laboratory studies, particularly if the two conflict. However, in reaching any judgement about the potential health risk associated with an exposure, a number of questions should be asked,⁵⁰ such as the following.

- Are the results of the epidemiological studies consistent?
- Is the **time relationship** between the exposure and the disease consistent with a possible causal relationship (ie, did exposure precede the disease)?
- Does the size of any effect, or risk of disease, increase with increasing exposure?
- How big is the **relative risk**? That is, what is the size of the relationship between the exposure and the disease or effect?
- Have experimental results been replicated in different laboratories?
- Did experiments follow good laboratory practice? For example, did they compare results for exposed animals against controls and undertake blind analyses so that the researchers' own biases do not affect their judgements?
- How good was the exposure assessment (dosimetry)? For example, were field levels measured, or inferred from a factor that may be imperfectly related to exposure (such as distance to a power line)?
- Are the results of the laboratory and epidemiological studies consistent with each other? If not, what are possible reasons (eg, differences in dose/exposure, species differences)? What relative weight should be accorded to the discrepant studies?
- Was the number of subjects (laboratory animals or people) in the studies adequate?
- Could results have arisen by chance or because multiple statistical comparisons were carried out?
- Were the correct statistical tests used and were they applied correctly?
- Are confounding, selection bias or information bias possible reasons for the results of the epidemiological studies?
- Do the results seem biologically plausible and consistent with the other information about the disease and knowledge of how the agent interacts with the body?

⁵⁰ These include the so-called 'Hill criteria' (Hill 1965), sometimes referred to as the 'criteria of causation'.

If several similar studies have been carried out but involve small numbers of subjects or animals, it may be possible to combine their findings through meta- or pooled analysis. The combined analysis gives greater power to detect a small effect or allows the size of an effect to be determined more precisely.

Systematic review

Just as there are recognised good practices in carrying out laboratory and epidemiological studies, there are also good practices for combining data from many studies to draw conclusions about if, or how, exposures to the agent of interest might affect health. The aim of a systematic review is to make the process as objective as possible, so that conscious and unconscious biases do not affect the conclusions. Procedures should be specified before the review is started, and preferably registered on an online database to provide transparency. Several organisations have prepared guidelines for undertaking such reviews, including the WHO (2014).

Typically a systematic review includes the following steps.

- **Statement of the research question:** This is used to guide the scope and conduct of the review. It often follows the 'PECO' approach: defining the Population of interest (eg, members of the general public or a particular occupational group), the Exposure of interest (eg, measured exposure to magnetic fields in the home), the Comparator group (eg, people with low magnetic field exposures) and Outcomes (eg, motor neurone disease).
- **Literature search:** Relevant databases will be searched using pre-defined search terms to find research papers related to the research question. This will normally include the use of inclusion and exclusion criteria to select the papers that are directly relevant to the question.
- **Data extraction and quality assessment:** A standard set of information is extracted from each study and the quality of each study is assessed. (The quality assessment is sometimes referred to as 'risk of bias'.)
- **Data analysis:** This could involve undertaking a meta-analysis using the extracted data, or making a more qualitative analysis of the data. It may also include additional analyses such as a sensitivity analysis (which would determine whether any of the included studies has a particularly large influence on the data analysis) or to see whether the findings might be affected by publication bias.⁵¹

The Health Council of the Netherlands (2014) review of animal studies on carcinogenesis provides a succinct example of a systematic review. Protocols for systematic reviews being carried out for the WHO monograph on RF fields are available online (Ijaz et al 2021).

The contrast between the conclusions drawn from systematic review and those drawn from a discussion of a small, selected subset of the literature (sometimes referred to as 'cherry-picking the literature') is highlighted by Elwood and Wood (2019b).

⁵¹ Publication bias occurs when the findings of a paper affect the publisher's decision on whether or not to publish it. There is often a bias against publishing negative results.

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

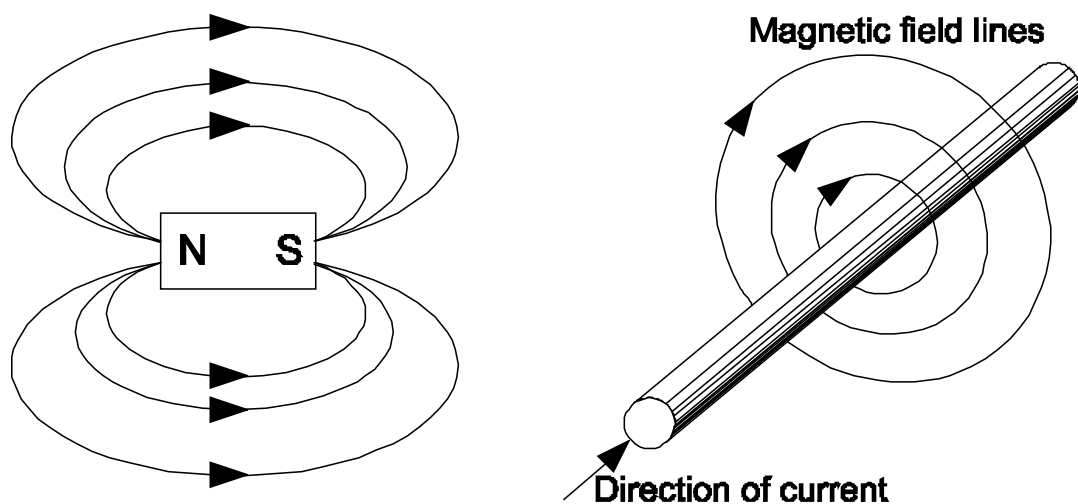
ELF fields

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 H1.

Figure H1: Magnetic field around a magnet (left) and a wire carrying an electric current (right)



If the current through the wire is not steady, changing 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.

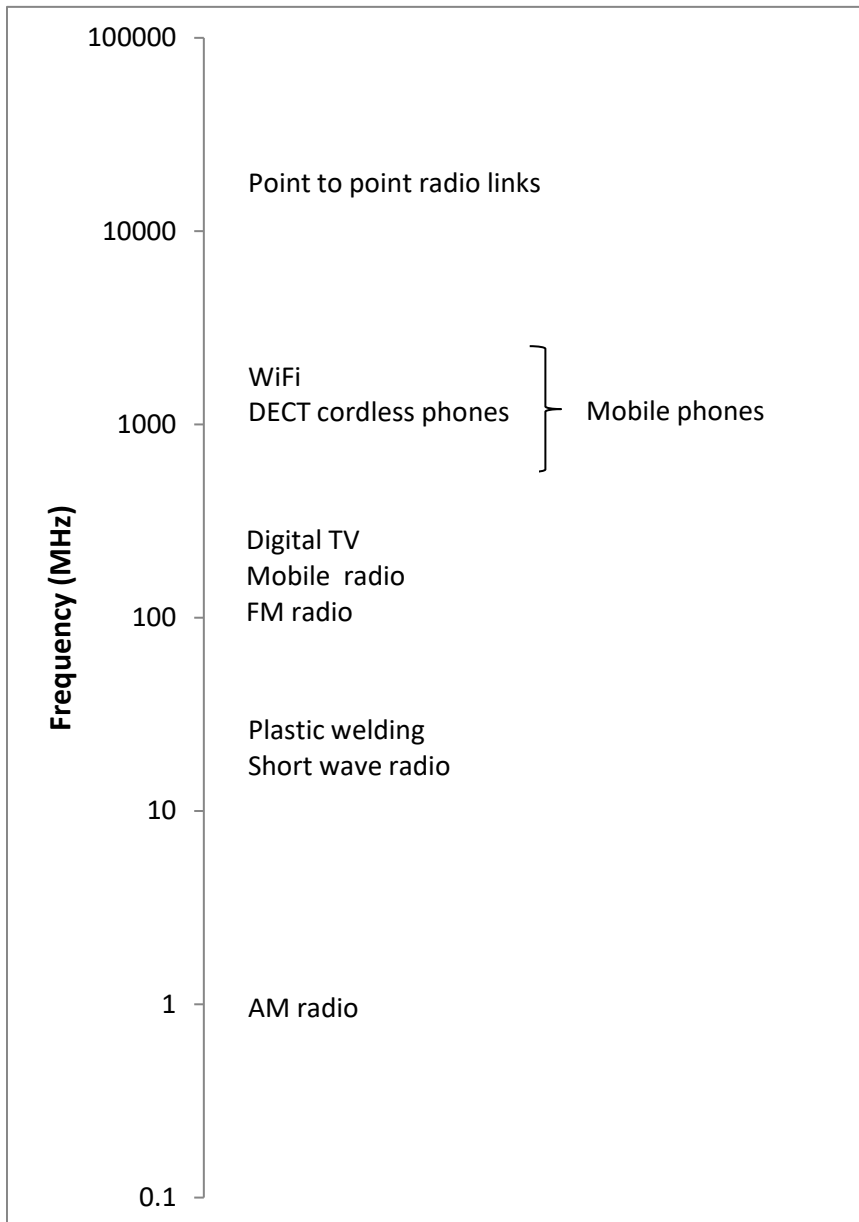
More generally, ELF is taken to cover frequencies up to about 100 kilohertz (kHz). (This was the upper end of the frequency range considered in the WHO (2007) review discussed in Section 3.2.) However, some discussions may only consider a lower maximum frequency. The sources that are usually of most 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 H2 shows the main applications of radiofrequency fields as a function of frequency.

Figure H2: 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 also 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.⁵² The parameters refer to the wave-like properties of EMR. Their meaning can be visualised by thinking about 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 radio waves 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, such as the ELF fields found around anything that carries mains electricity. 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.⁵³ 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).

⁵² Frequency \times wavelength = 3×10^8 .

⁵³ 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 extend only 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.

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).