Towards National Guidelines for Managing the Effects of Radiofrequency Transmitters: Discussion document

Prepared by the Ministry for the Environment, in partnership with the Ministry of Health

Executive summary

In March 1998 the Government directed the Ministry for the Environment in partnership with the Ministry of Health, and following consultation with interested groups, to draft national guidelines on managing the health effects of radiofrequency transmission facilities.

Since the Government's direction for national guidelines, the Environment Court has issued its ruling on the *Shirley Primary School v Telecom Mobile Communications Ltd* [1999] NZRMA 66. This decision provides guidance on many of the contentious issues associated with the debate on the siting of radiofrequency fields. The Ministries for Environment and Health consider that there is still value in providing national guidance on managing the health effects of radiofrequency fields, in order to:

- increase public understanding of how radiofrequency transmission facilities operate and how international exposure standards are developed;
- provide the Ministry of Health's advice on health effects;
- encourage a consistent approach by territorial authorities in managing the effects of radiofrequency transmission facilities;
- encourage industry to reduce community concern through non-regulatory approaches; and
- ensure people are aware of the implications of the Environment Court decision.

The first section of the guidelines document outlines the key issues raised during initial consultation with industry representatives, community groups and territorial authorities.

The next two sections provide information on radiofrequency technology and how scientists determine whether there are adverse health effects associated with radiofrequency transmitters. During initial consultation it became apparent that a lack of understanding of these issues is contributing to the public's concern about where these facilities are sited. This will enable people to consider the issues in an informed way.

This is followed by advice on health effects and appropriate exposure levels. The Ministry of Health recommends strict application of the exposure guidelines published in 1998 by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) which have been incorporated in the 1999 New Zealand radiofrequency fields exposure Standard. The Ministry of Health considers there are no established adverse effects from exposures to radiofrequency fields which comply with the ICNIRP guidelines and the New Zealand Standard.

Even if future research does eventually show that health effects exist, the risk from exposures to radiofrequency fields is likely to be very small or negligible. In view of the residual scientific uncertainty and the impossibility of proving any agent completely safe, where possible, low-or no-cost interventions should be applied in order to avoid or reduce exposures. However, this should not be done by arbitrarily imposing exposure limits lower than those recommended by the voluntary NZ Standard.

If there are different options available when designing or siting a radio transmitter, then those resulting in the lowest incidental exposures around the site should be chosen, all other things being equal. These measures could include minimising transmitter power to that required to achieve coverage objectives, choosing or designing antennas which minimise emissions in directions not required for coverage, and (if alternative sites are available or if there are different options for mounting antennas on a single site), selecting the option that results in the lowest exposures.

Section five provides a summary of recent case law from the Environment Court on issues such as: health effects; the precautionary approach; and the relevance of considering psychological effects and reduced property values. These cases set important precedents for all territorial authorities.

The final sections of the guidelines provide specific guidance to the three key players in the debate: territorial authorities, industry, and the public.

The section for territorial authorities provides advice for district plans on managing the health effects of radiofrequency fields. This will encourage a consistent approach being taken on health effects. The guidelines recommend that an activity be a permitted activity if exposures to radiofrequency fields in areas normally accessible to the public are estimated not to exceed 25 percent of the exposure limit for the general public set in NZS 2772.1:1999. If radiofrequency exposures are estimated to exceed 25 percent of the limit, but still comply with the limit in NZS, the activity would be a controlled activity.

This allows for an additional assessment of radiofrequency exposures if initial modelling predicts that they will exceed 25 percent of the limit. This takes account of the potential for actual exposure to increase because of manufacturing tolerances in equipment and reflections of radio signals off some surfaces. Reflections can cause localised increases or decreases from calculated levels.

This section also recommends that the telecommunications industry be encouraged to voluntarily minimise exposures to the public.

The section for applicants – that is, for the telecommunications industry - suggests that there are actions it could take to reduce community concern about siting.

- Recognise that there is value in communicating with concerned residents
- Recognise that particular skills are necessary for communicating with concerned people effectively
- Address community concerns where this involves no- or low-cost action.

While the Ministry for the Environment and the Ministry of Health agree that it is essential to ensure the credibility of the NZ Standard and ICNIRP guidelines and assure people that there will be no health effects if they are complied with, they see no reason why industry could not provide people with additional assurances by publicising any commitment to best engineering practice. In this way, industry can demonstrate to people that it is actually in industry's own business interests to minimise exposures.

The final section provides advice to communities on the implications of recent Environmental Court case law. It emphasises that the *Shirley* case – which found that a very low probability of potential adverse health effect was not sufficient for denying a resource consent for siting a cellphone transmitter - acts as a precedent and that further appeals on health issues are unlikely to be successful.

The section also outlines how the Ministry for the Environment and the Ministry of Health intend to address the lack of information for the public on radiofrequency issues. The two Ministries:

- will provide technical and scientific information in these guidelines;
- support the telecommunications industry/community group suggestion that a nationwide monitoring programme of randomly selected sites be initiated to provide the public with more assurance that these facilities operate within international standards; and
- propose to establish an interagency committee, reporting to the Director-General of Health, to report on future research.

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1 Introduction

In March 1998, the Government directed the Ministry for the Environment in partnership with the Ministry of Health, and in consultation with interested groups, to draft national guidelines on managing the effects of radio-frequency transmission facilities. The guidelines must include guidance on:

- exposure levels
- resource management plans and processes
- monitoring
- risk management and communication
- any other issues arising from consultation.

The Ministry of Health is responsible for guidance on health effects. The Ministry for the Environment is responsible for guidance on resource management issues. The Ministries have consulted with representatives from community groups, the telecommunications industry and territorial authorities throughout the development of draft national guidelines. During 1999 and following the analysis of submissions from this discussion document, final national guidelines will be published.

1.1 Issues identified through consultation

Summaries of the issues identified by community groups, the telecommunications industry and territorial authorities are attached in Appendix A. The following summarises the key issues each group identified as contributing to the debate on siting of transmission facilities.

Community groups

- It is difficult for communities to determine whether or not radiofrequency transmission facilities are safe when there appear to be conflicting opinions amongst scientific experts on whether or not there are health effects. Credible guidance from central government is needed.
- There is a divergence of views amongst community groups about whether radiofrequency transmission facilities should be developed unless they are proved to be totally safe.
- International research on the potential health effects of radiofrequency fields is taking place. There is concern that there is no independent organisation in New Zealand reviewing the research literature and providing updates for the public.
- Communities consider they are not having adequate input into siting decisions. They feel that generally industry does not consult about the siting of transmission facilities before applying for resource consents. There is also a community perception that applicants are not always honest about the options or the technological constraints.
- Communities feel that resource consent processes do not provide sufficient opportunities for opposing parties to discuss issues.
- Communities consider that decisions on resource consents are not always made by independent, impartial decision-makers.

- Insufficient monitoring of transmission facilities is occurring. Some communities are concerned that they do not have enough information on emission levels from existing sites. Communities are concerned that some requiring authorities are not acting responsibly.

Industry

- Industry considers that communities need to be educated about health effects in relation to radiofrequency transmission facilities. It is difficult for the telecommunications industry to correct misinformation, as it is perceived as having a vested interest.
- Central government needs to provide guidance on whether or not there are established or potential health effects based on sound scientific evidence associated with radiofrequency transmission facilities.
- Community concern increases costs for industry.
- Industry feels that territorial authorities do not have expertise on health effects and should rely on advice from the Ministry of Health.
- Industry also feels territorial authorities are not taking a consistent approach to managing the effects of radiofrequency transmission facilities.
- There is concern that monitoring of every radiofrequency transmission facility would be expensive for industry and that industry would prefer representative sites for monitoring to be established.
- There is a need for a core set of contacts which communities, territorial authorities and industry could use for advice on health information.

Territorial authorities

- Some territorial authorities feel they lack the in-house specialist expertise needed, particularly in relation to health effects, interpreting scientific information, and monitoring exposures to radiofrequency fields.
- The Resource Management Act 1991 (RMA) provides constraints which are misunderstood by the public and applicants.
- Guidance is needed on best practice in relation to rules and performance standards. It would also be useful to be aware of the approaches different territorial authorities have taken on this issue.
- Guidance on defining affected parties and notification is required.
- Preparing for hearings/appeals is expensive.
- Territorial authorities have questions about monitoring: how much, how, when, where, by whom?

1.2 Key issues to be addressed in national guidelines

Since the Government's direction for national guidelines, the Environment Court has issued its ruling on the Shirley Primary School case. This decision provides guidance on many of the contentious issues associated with the debate on the siting of radiofrequency fields. (A summary of the decision can be found in Appendix G6.)

The Ministry for the Environment considers that there is still value in providing national guidance on managing the effects of radiofrequency fields, for:

- ensuring people are aware of the implications of the Court decisions
- increasing public understanding of how radiofrequency transmission facilities operate and how international exposure standards are developed
- providing the Government's view on health effects
- encouraging a consistent approach by territorial authorities to managing the effects of radiofrequency transmission facilities
- encouraging industry to reduce community concern through non-regulatory approaches.

During consultation it became apparent that a lack of understanding of radiofrequency technology and how scientists determine risk was contributing to people's concern about the siting of radiofrequency transmission facilities. The first two sections of this report therefore attempt to better enable people to consider the issue in an informed way by providing objective information on:

- how radiofrequency technology works
- the factors affecting a person's exposure to radiofrequency fields
- typical exposure levels associated with various radiofrequency technologies
- how scientists evaluate apparently conflicting evidence in health effects
- the development of international exposure standards.

This is followed by guidance on the Government's position on health effects and international exposure standards. In response to issues raised during consultation, advice on other environmental effects is also provided. This includes a detailed summary of recent case law from the Environment Court.

In the final three sections of the guidelines, specific guidance is provided to the three key players in the debate:

- The section for territorial authorities provides advice on managing the health effects of radiofrequency fields through district plans. It is hoped that this will lead to a consistent approach being taken on health effects.
- The section for the telecommunications industry suggests that non-regulatory actions are likely to be an important part of reducing community concern about siting.
- The final section provides advice to communities on the implications of recent environmental case law and actions which could be taken, which are consistent with the philosophy of the RMA to address their concerns about radiofrequency fields.

1.3 Relationship between national guidelines and the territorial authority project on monitoring

At the same time as the Ministries of Health and Environment were directed to prepare these guidelines, a group of four territorial authorities received funding from the Sustainable Management Fund (SMF) to provide guidance for territorial authorities on issues relating particularly to cellsites.

The Ministries and the territorial authority group have liaised throughout the development of these guidelines to ensure that the two documents provide consistent advice. The SMF report, which will be attached to the final guidelines, provides detailed technical advice for territorial authorities on monitoring the effects of radiofrequency fields, data information management and guidance on educating the public about radiofrequency fields.

2 Radiofrequency fields and technology

2.1 Radiofrequency fields

An increasing amount of modern communication uses radio waves, formed from radiofrequency electric and magnetic fields. This includes AM and FM radio, television, remote-control devices (such as garage door openers), radio telephones, walkie-talkies, and cellphones. Unlike systems such as conventional phones, there is no need for a physical link (such as a wire or fibre optic cable) between the sending and receiving points.

All these systems need transmitters, from which the radio waves are transmitted to the receiving equipment. While "conventional" radio and TV transmitters are familiar newer technology, particularly that needed for cellphones, has given rise to concern in some areas. The health considerations are addressed in other sections of this document. This section gives a brief technical background. See also the Glossary for further definition of some of the terms used.

Transmitters operate at different *frequencies*, depending on the application. There are national and international rules and conventions which allocate frequencies for different purposes (eg, for TV and radio transmissions, medical and industrial applications) to ensure that suitable frequencies are available for each purpose, and that different users do not interfere with each other. Figure 1 maps these various devices against the amount of power needed for the application.

FM and AM radio and TV transmitters operate at comparatively high powers (several kilowatts). Cellsites (particularly in urban areas) and radio telephones operate at moderate to low powers. Microwave systems used for point to point communications operate at low power. As will be discussed in section 2.1.2, the power of a transmitter is only one factor which affects exposures to the radiofrequency fields it produces.

A transmitter has two main parts: the radiofrequency source itself, which generates the radiofrequency energy to be transmitted, and an antenna from which the radio signals actually propagate. (If the antenna is some distance away from the radiofrequency source, the two may need to be linked by special cables.)

Simple antennas, such as the ones used on a cordless phone or for some mobile radios, transmit fairly equally in all directions. But it is often best to transmit more energy in some directions than others. For example, a TV transmitter may use directional antennas. These will aim the radiofrequency signals towards the TV audience, rather than wasting signals on areas where there are no TVs. The TV station will get the same coverage - and use less power - than they would in broadcasting the transmission equally in all directions.

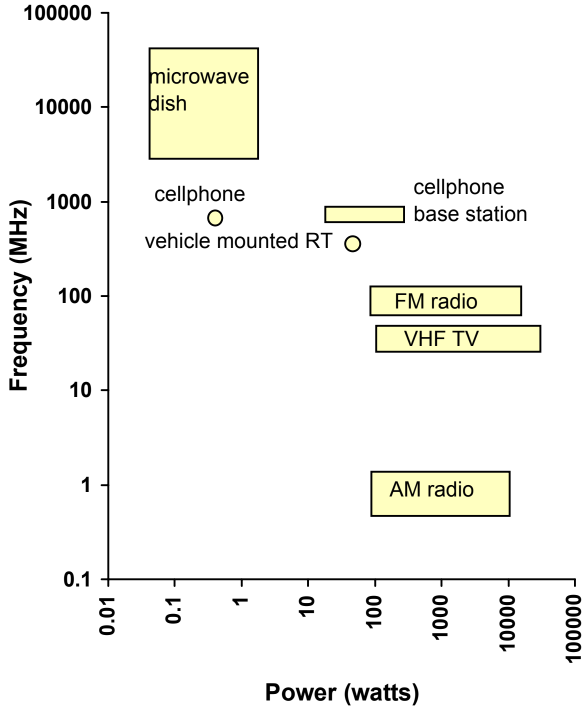

Figure 1 Frequency and power of different radiofrequency sources

2.2 Exposures from radiofrequency transmission facilities

2.2.1 Factors affecting exposures

Exposure to the radiofrequency fields produced by a source depends on a number of factors. The main ones are outlined below.

Distance: Strength of the fields decreases with increasing distance from the source, just as sounds (also carried by waves) are quieter as you get farther from the source. Generally, exposures decrease with the inverse square of the distance; someone 2 km from a source receives one quarter the exposure of someone only 1 km from the source.

Transmitter power: In any given situation, stronger transmitters produce higher exposures. If a transmitter power doubles, exposures around the transmitter also double.

Directionality of antenna: Antennas can be designed so that radio signals which would otherwise be transmitted in directions where they are not required for achieving the desired coverage (eg, straight down towards the ground, or up to the sky) are redirected towards areas where they are needed. Because less of the signal is wasted, a lower power transmitter can be used than if a simple, non-directional antenna had been used. The amount by which the antenna increases the amount of power transmitted in any direction, compared to the amount which would go in that direction if a simple antenna were used, is referred to as the *antenna gain*.

Height of the antenna above the ground: Increasing the height of an antenna above the ground is another means of increasing distance from the antenna, and exposures in any given direction will decrease.

Local terrain: The terrain can cause exposures to vary considerably from what they would be if the ground were flat. Many types of transmitter- for example, for FM radio, TV, cellsites, microwave communication systems - ideally require a direct line of sight to pick up the signal. Trees, buildings or intervening ridgelines markedly reduce exposures.

Exposures to radiofrequency fields are usually described in terms of *power flux density* and are measured in microwatts per square centimetre ($\mu W/cm^2$). (See Glossary.)

Power flux density is related to both the electric and magnetic field strength, and in most cases is sufficient to describe exposures to radiofrequency fields. The main exception which concerns these guidelines is within 100-200 m of AM radio transmitters, where the normal relationship between power flux density and electric and magnetic field strength does not apply. In such situations, electric and magnetic field strength must be considered separately.

2.2.2 Measuring absorption of radiofrequency fields

Radiofrequency power actually absorbed in the body is quantified as the *specific absorption rate* (SAR – see Glossary), measured in watts per kilogram (W/kg). SAR is widely accepted as the fundamental unit of the "dose" of radiofrequency power received by the body and helps in comparing exposures at different frequencies (or in trying to extrapolate to people the results of experiments in which animals are exposed to radiofrequency fields).

In exposure standards, a limit on SAR is often specified as the basic restriction on exposures to radiofrequency fields. From this, equivalent limits in terms of the more easily measured power flux density (or radiofrequency electric or magnetic field strength) are derived.

The amount of radiofrequency power absorbed in the body depends not only on the power flux density, but also on the frequency of the signal. To a radio signal, the body acts like a receiving antenna (albeit a rather poor one). For a given power flux density, the body absorbs more power at frequencies around 100 MHz than at higher or lower frequencies.

2.2.3 Exposures from radio transmitters

Because exposures depend on several factors, it is not always obvious what the exposures will be in any situation. For example, a major TV or FM radio transmitter is quite powerful, so at first it might appear that exposures around it might be quite high. But the antennas on such transmitters are usually mounted quite high above the ground and direct most of the signal away horizontally, and comparatively little is directed steeply down to the ground around the base of the transmitter. In practice then, exposures are quite low.

In comparison, cellphones are fairly weak transmitters, but because they are held right next to the head, exposures can be relatively high.

Table 1 shows factors affecting exposures for different types of transmitter, and typical exposures that might be expected. These exposures are what might be expected outdoors. Exposures in buildings would normally be much lower, except near windows facing the transmitter. For most types of transmitter, except AM radio, the maximum exposures tend to occur in isolated spots.Even close to the transmitter, exposures would generally be lower.

There is not yet enough data to say what typical "ambient" levels in New Zealand are. A 1980 survey of FM radio and VHF TV transmitters in major US cities found a median exposure of 0.005 $\mu W/cm^2$, and 1 percent of the population studied (about 400,000 people) were found to be exposed to levels greater than 1 $\mu W/cm^2$. It is expected that New Zealand exposures would be similar to, or somewhat less than, these values. The territorial authority report funded from the Sustainable Management

Fund referred to in Section 1.3, which will accompany the final version of these guidelines, should provide further information on this point.

Table 1 Factors affecting exposures for different types of transmitter, and typical exposures that might be expected

Transmitter type	Factors which tend to increase exposures	Factors which tend to decrease exposures	Typical exposures in public areas ($\mu W/cm^2$)	ICNIRP/NZS exposure limit
FM radio	High power	Antenna mounted up high (~100 m) towers Directional antennas, emissions mostly horizontal rather than at steep angles towards the ground Normally in thinly populated areas	Close to transmitters: maximum 1-10 A few km away: 0.1 - 0.3	200 $\mu W/cm^2$
TV	High power	Antenna mounted up high (~100 m) towers Directional antennas, emissions mostly horizontal rather than at steep angles towards the ground Normally in thinly populated areas	Within 500 m of transmitters: maximum 1-10 A few km away: 0.1 - 0.3	200 $\mu W/cm^2$
AM radio	High power Antenna at ground level	Normally in the middle of large open areas	Within 20 m of antenna: 100-1000. More than 1 km away: less than 1	2,200 $\mu W/cm^2$
Cellsite	May be within a few m of the ground.	Moderate to low powers. Directional antennas, emissions mostly horizontal rather than at steep angles towards the ground. Terrain and buildings often block direct line of site, and shield signals	Within 50 m of sites: maximum 1-10 More than 100 m: less than 1, often less than 0.1	450 $\mu W/cm^2$
Mobile radio base sites	Older equipment uses fairly undirectional antennas	Moderate to low power Tends to be sited on sparsely populated hilltops, up a mast.	Within 50 m: maximum 1-10 More than 100 m: less than 1, often less than 0.1	200 $\mu W/cm^2$
Microwave dishes (point to point)		Low power Highly directional antennas, transmitting focused beam away from the ground or buildings. Antennas mounted on buildings or up towers.	Less than 0.05 everywhere, generally less than 0.001.	1,000 $\mu W/cm^2$

2.2.4 Exposures from cellsites

As exposures from cellsites have been at the heart of many people's concerns, they are discussed in more detail here.

Cellsite antennas normally transmit most power horizontally away from the antenna (or just below the horizontal), with comparatively small amounts directed at steep angles towards the ground. In Figure 2, the black rectangle represents a panel antenna (a type frequently used at cellsites) mounted on a pole. The relative exposures in different directions are represented by the depth of shading. The greatest exposures are directly in front of the antenna, in the main lobe of the beam. There are also two side lobes, one pointing down and one up at the sky. The side lobes result from the design features that focus most of the power into the main lobe. Different antenna designs may have different side lobes.

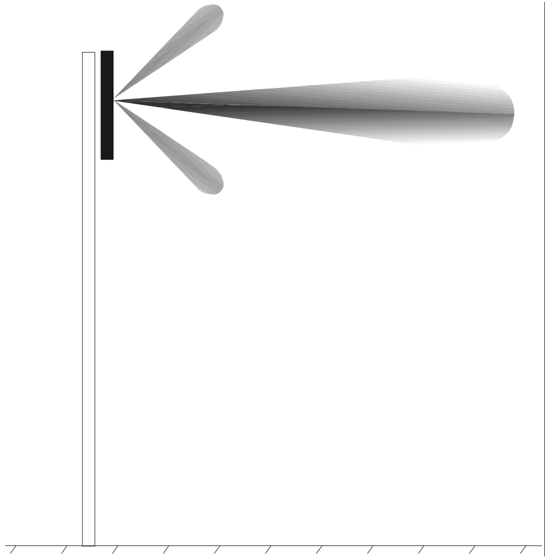

Figure 2 Power transmission from a cellsite antenna

Figure 3 plots the variation of radiofrequency exposure with increasing distance from an antenna of the type illustrated above. The curve maps the exposure to someone on the ground who starts at the base of the antenna's pole and walks away from it.

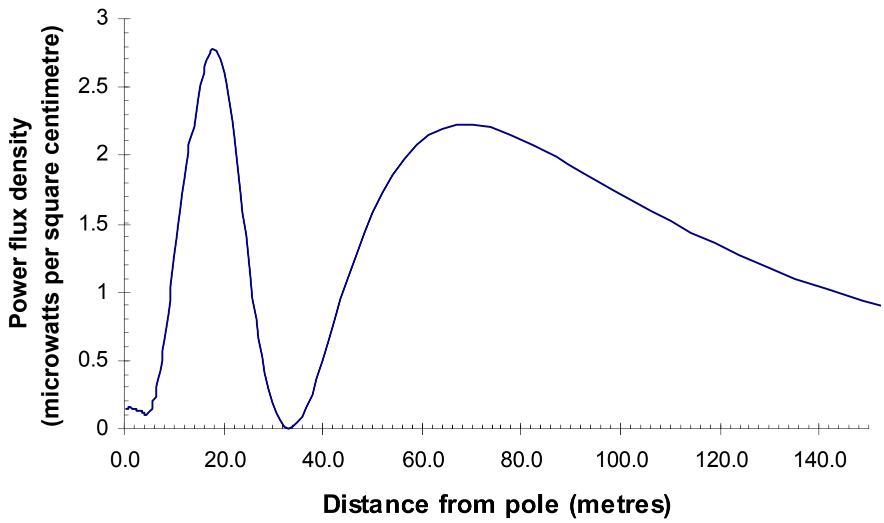

Figure 3 Exposure to someone walking away from the base of the pole

Exposures at the base of the pole are very low. As the person walks further away, the exposure rises, reaching a maximum about 20 m from the pole, and then decreases again. This increase in exposure corresponds to the point where a sidelobe from the antenna beam intersects the ground.

Beyond 30 m, the exposure rises again, reaching a second maximum about 70 m from the pole. Thereafter, the intensity decreases with increasing distance, approximately following the inverse square law mentioned earlier (eg, exposures 200 m from the pole are a quarter of what they are 100 m from the pole).

Tests made under ideal conditions (such as a cellsite in the middle of a large open field) show that measured exposures do generally agree with the predicted values. However, over short distances (10-20 cm) the measurements may vary both above and below the theoretical values. These variations are due to reflections of the radio signal off the ground, and generally average out.

Although this example is for a particular antenna type, pole height and transmitter power, it illustrates the general features of exposures around a cellsite.

Exposures in the Wellington suburb of Wadestown, where there are two cellsites within about 100 m of each other, are mapped in the figure below. It was evident during this survey that in places there was an additional contribution from the TV and radio transmitter on Mt Kaukau.

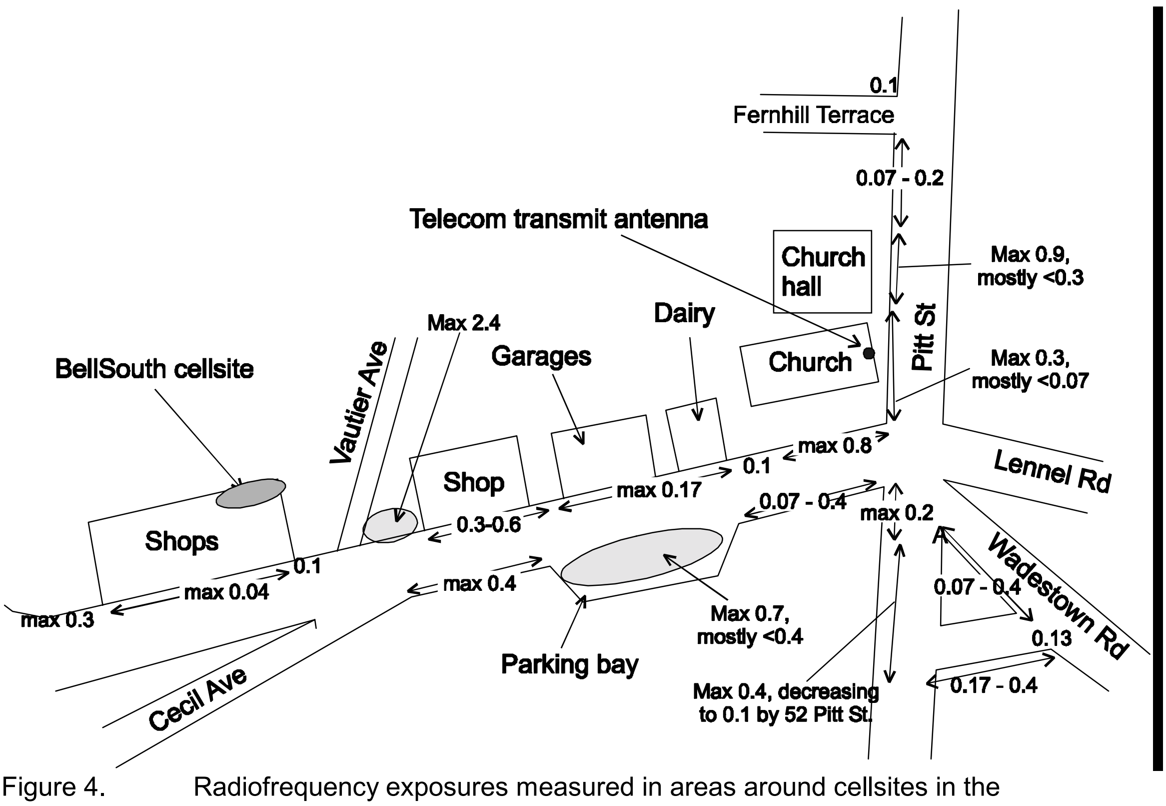

Figure 4. Radiofrequency exposures measured in areas around cellsites in the Wadestown suburb of Wellington. Figures give power flux density in microwatts per square centimetre. (Note that the exposure limit for cellsites is 450 microwatts per square centimetre.)

2.3 Changing technology

Changes anticipated in broadcasting technology over the next few years, and their possible effects on radiofrequency exposures, will include those listed below.

- *Increased capacity requirement for existing cellular networks*: Cellsites have limited capacity to handle calls. When the number of users in a cell (the area covered by a cellsite) exceeds the capacity to handle calls, the cell must be split into smaller microcells, each serviced by its own site. Microcells are already operating in central Auckland. The infrastructure required is smaller than for a normal cellsite, and microcells normally operate at lower power. However, as the antennas may be closer to the ground than for a normal site (eg, mounted on traffic lights), exposures to the radiofrequency fields they produce may be comparable. Depending on how the cellular network has developed, existing sites may or may not still be required to provide umbrella coverage over the area served by a number of microsites.

- *Advent of PCS (personal communication system) technology*: PCS is a development of current cellular technology, using higher frequencies (1800 MHz, rather than 900 MHz). It is best suited to areas requiring a high density of coverage, and in many respects would simply augment present cellphone networks. Some implementations permit additional features, such as hybrid phones, which function as a cordless phone in the owner's house but as a cellphone elsewhere.

- *Satellite technology*: Two-way communication via satellite is becoming increasingly common. The land-based end of the link is a dish antenna, which must be aimed carefully at the satellite, and both receives and transmits. Dish antennas are very directional, rather like a searchlight beam, and exposures outside the beam are very low. For most applications, the beam from the dish must be aimed well above the horizontal, and chances of unintentional exposures are low. These applications are not the same as one-way services like satellite-based TV transmitters, whose signals are picked up by dish antennas. Such receiving antennas, like standard TV antennas, are entirely passive devices and do not produce radiofrequency fields themselves.

- *Digital broadcasting*: Digital transmission of some TV channels will start in about 2000. A digital channel can achieve the same coverage as a conventional analogue channel at lower power. Even though digital transmission may lead to an increase in the total number of TV channels being transmitted, in the long term there is likely to be a net decrease in transmitter power. However, as both analogue and digital channels will be transmitted during the transition to full digital broadcasting, there may be about a 10 percent increase in total transmitter power in the medium term.

Despite rapid changes in technology, health advice given in these guidelines will remain relevant. The nature and effects of the radiofrequency fields they are expected to produce will be the same as those of existing types of transmitter.

3 Health effects and exposure standards

3.1 Understanding the science

Consultation during development of these guidelines shows that there is not yet a good understanding in the community about how scientists assess whether health effects from exposures to radiofrequency transmission facilities are likely to exist or as to what levels of exposure are generally regarded as safe. There was also confusion about how scientific evidence was used, in conjunction with societal judgements on levels of acceptable risk when developing policy to improve, promote and protect public health.

The considerations discussed in this section will be useful for understanding how the results of studies on the potential for radiofrequency fields to cause health effects are assessed. The section presents some issues that are taken into account in such assessments and also outlines some of the complexities and pitfalls that can arise. Although the focus here is on radiofrequency fields, the comments are common to assessing other environmental exposures for possible health effects.

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

Modern society wants to experience the benefits of technologies, and many of these 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. It is not up to scientists alone to make the risk-benefit judgements. Where scientists can help is in supplying information that can ensure that such judgements are reached with the use of the fullest information possible.

The best that scientists can offer is evidence of a high level of consistency in the results of a wide range of studies of various types showing no evidence of likely health effects. Only rarely do studies of any one form of exposure produce uniformly reassuring results in a wide range of different types of test. Often, some tests will show no evidence of harm, whereas others of a different type may 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 no resolution of discrepancies can be achieved - decide on how much weight should be given to conflicting results.

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 scientific controversy, the actual disagreement may be less than it seems. The great majority of scientists may hold one particular point of view and a small minority another. Sometimes the alternative viewpoint may be more newsworthy, which means that the public may not get a clear sense of where the weight of scientific opinion lies.

In general terms, there are three broad categories of scientific study which can contribute to resolving the scientific debate over exposure to radiofrequency 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 observation. All three have value in assessing health risk, and all three have their advantages and disadvantages. Particular advantages and disadvantages for the three categories of study are briefly described below.

3.2 Laboratory studies (experimental)

3.2.1 In vitro studies

In vitro studies (Latin, "in glass") take place in the laboratory and take place 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 take place in complete organisms (including, of course, human beings). Thus, they cannot demonstrate effects that would occur in whole organisms, although they may well suggest what effects there might be. Such suggestions need to be followed up with studies using whole animals or with epidemiological studies.

In vitro studies are probably most useful for investigating findings that may be suggested by *in vivo* laboratory or epidemiological studies, but which in themselves can not provide definitive evidence of health effects. However, such studies may raise possibilities that deserve further investigation.

3.2.2 *In vivo* studies

In vivo ("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 prediction of effects on humans. Generally, they involve groups of animals subjected to different degrees of exposure to radiofrequency fields, while all other factors are held constant.

A particular advantage of *in vivo* studies is that the degree of radiofrequency fields exposure of the animals can be controlled and measured very precisely.

Disadvantages of these studies are that the animal species (often rats and mice) are frequently different to 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 are actually affected by the exposure, that will still represent a large number of people, but this same percentage would be difficult to detect with any degree of statistical confidence using only a few hundred animals. (See also Section 3.3.) Thus, to compensate for the relatively small number of animals and to increase the chances of detecting any effect, high exposure levels are used.

Furthermore, 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 combination possibilities, it is not feasible to test all (or even a fraction) of these in animal studies.

3.2.3 Replicability

A key consideration in assessing the results of *in vitro* and *in vivo* studies is whether the experimental results are replicable (ie, repeatable), particularly whether they are replicable 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 first experiment cannot be assumed to apply anywhere else.

As with *in vitro* studies, replicability of *in vivo* results is important, including generation of similar results 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.

3.3 Epidemiology studies (observational)

These take place outside the laboratory, in the world at large. Occupational and environmental epidemiology studies are studies of populations of people, and they are made in order to investigate the relationships between exposures and health outcomes.

–They study human health by observing human beings - whereas laboratory studies may involve use of other animals or of tissues and cells. These studies involve levels of radiofrequency exposures to which humans are actually exposed.

3.3.1 Exposures

Apart from the appropriateness of species and radiofrequency exposure levels, there is another key distinction between epidemiological studies of radiofrequency exposure and laboratory (*in vitro* or *in vivo*) studies. Laboratory studies are carried out in very 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.

On the other hand, environmental epidemiological studies into health effects from exposures to radiofrequency fields cannot usually control exposures. As well, every person is subject to their own individual set of exposures (physical, chemical, biological and social), 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 they can only observe and estimate the level of those exposures. In an *experimental* situation, every effort is made to control and precisely measure exposures but most diseases, including cancers, are believed to have more than just one cause. The risks of many or most human diseases may be influenced by a range of different exposures or combinations of such exposures. These exposures, or their combinations, may be protective or harmful.

3.3.2 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 (but not all) are causal factors for the disease. Multiple exposures can result in non-causal exposures appearing to be associated with the disease, if they occur with actual causal exposures. For example, cigarette smokers have often been shown to be more likely to be coffee drinkers than non-smokers. Unless smoking behaviour were taken into account in analysing the results of such an epidemiological study, then coffee drinking might appear to be a cause of lung cancer and the numerous other diseases associated with cigarette consumption.

For radiofrequency fields, confounding might arise, for example, if a population around the site of a radiofrequency transmitter such as a television tower were of a different socio-economic group to the comparison population. Since many cancer risks are related to socio-economic factors, then the population around the television tower might appear to have a higher cancer rate if the socio-economic factors were not properly taken into account in the analysis.

3.3.3 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 selection and information bias. **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 "something is happening", 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.

3.3.4 Multiple comparisons

Another consideration is whether results could be due to chance or random variation in the population being studied. The effects of chance are always a possibility when the study population or the number of health events is small. Statistical tests have been developed to investigate the likelihood that chance may be an important factor.

However, when many statistical tests are carried out, as in the not-uncommon situation where a wide range of diseases is being investigated for association 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, although well designed studies avoid trawling expeditions. It is also the case that even highly statistically significant results may be caused by bias or confounding, and such possibilities need to be thoroughly investigated.

3.3.5 Consistency of results

Because unknown bias (particularly confounding) may always be affecting the results of epidemiological studies, epidemiologists have developed a number of criteria to assess studies once best efforts have been made to minimise the possibility that chance or bias may be key factors influencing study results.

One of the most important of these is consistency of results of different epidemiological studies carried out with different study populations. Consistency of epidemiological findings corresponds to the replication of results of experiments in different laboratories. The idea behind the consistency criterion is that if epidemiological studies are inevitably subject to the possibility of chance variation and bias, then similar results obtained by different studies with different populations makes such influences less likely. However, 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 one form of cancer is increased in one study and another form of cancer is increased in another study, that the two studies are consistent. All cancer types are different and will have different causes. Even within one category of cancers, such as leukaemias, there is a lot of variation in types. An increased rate of one type of leukaemia would not necessarily be consistent with an elevated rate of a different type of leukaemia in another study. Adult leukaemias may also be likely to have different causes than 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.

3.3.6 Other considerations

There are other considerations that need to be at least considered when considering the implications of the results of one or more epidemiology studies:

- Is the *time relationship* between the exposure and the disease consistent with a possible causal relationship?
- Is there evidence of a *dose-response relationship* between the disease and the exposure, that is does the 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?
- Is the alleged relationship between exposure and the disease *biologically plausible*?

Except for the requirement that a causal exposure must precede appearance of the disease, none of these is a necessary requirement for judging that there is a causal association.

3.4 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.

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

These include:

- Have experimental results been replicated in different laboratories?
- 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?

- Were 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?
- Are confounding, selection bias or information bias possible reasons for the results of the epidemiology studies?
- Are the results of the epidemiology studies consistent?
- Is there evidence that effects are dose/exposure-related?
- Are the time relationships between exposure and observed effects consistent with a likely association?
- Do the results seem biologically plausible and consistent with the other information about the disease?

3.5 Effects on health: current consensus

The extensive research literature investigating health effects of radiofrequency fields has been reviewed many times (for example, by the WHO (1993), Alistair Woodward et al (1996), ICNIRP (1997, 1998), the British National Radiological Protection Board (Cridland (1993), Dennis et al (1992), Saunders et al (1991)), Repacholi (1998)). These reviews have concluded that at frequencies above about 1 MHz, radiofrequency energy is converted to heat inside the body.

In most situations, such as in publicly accessible areas around radio transmitters, this heating is negligible compared with heat produced by the body's own metabolism, generally less than 0.0005 W/kg compared with 1-4 W/kg from metabolism.

At high exposures, where radiofrequency power absorbed by the body is similar to or greater than that produced by metabolism, the heating produces the same symptoms as heat distress and at very high exposures may eventually damage tissues. At exposures close to the heating threshold subtle alterations in the behaviour of experimental animals have also been reported. Although such exposure may occur from time to time in some occupations (for example, where staff use powerful radiofrequency generators to weld plastics), it would certainly be unusual and should normally be prevented by proper health and safety practices.

These effects are sometimes referred to as 'thermal effects'.

At even higher frequencies (above 10 GHz , or 10,000 MHz), exposures to very intense radiofrequency fields can produce cataracts or skin burns. Such exposures could only be experienced a few metres directly in front of powerful radar sets.

Radiofrequency fields at frequencies below about 1 MHz induce electric currents in the body. At low levels of exposure, these are still much lower than the currents produced by the body's own electrical activity (nerve signalling etc), but with higher exposures (such as could occur within a few metres of high-power AM transmitters), these may begin to interfere with nerve activity or cause shocks or burns.

There is a fairly wide consensus that exposures to relatively weak fields appear unlikely to cause short- or long-term health effects, but there are some scientists who disagree. Areas of disagreement related to low levels of exposure and to health effects other than tissue heating (often referred to as 'athermal effects') are discussed in Appendix B.

A great deal of research has already been carried out to find out if there are effects caused by low-level exposures. Nevertheless, we still need further work to try and resolve the areas where there is some disagreement, or areas where the data available is of uncertain significance. Some current and proposed projects are outlined in Appendix C.

3.6 Exposure standards

The scientific consensus on the health effects of radiofrequency fields has been developed over the past thirty years. It is based on reviews of all the relevant research. Such reviews have also formed the basis for developing exposure standards that will limit exposures to levels which will ensure a safe and healthy living or working environment.

Standards must be based on a review of the relevant research by people who can make a critical assessment of the findings. The exposure levels which are harmful, or are considered likely to be harmful, to human health must be determined. Exposure limits are set below such levels, and normally include a safety margin. The basis and limits must be clearly set out.

In recent years, several exposure guidelines or standards have been published internationally, including in the USA and Australia and New Zealand. USSR regulations were published in 1984 but have not been reviewed since then. The procedures involved in preparing some of these standards are set out in Table 2, below.

Table 2 Published standards

Organisation	ANSI*	Standards NZ	ICNIRP**	USSR Ministry of Health
Date	1992	1999†	1998	1984
Review committee	About 120 international scientists, membership open to any interested party .	Representatives from government departments, researchers, industry, trade unions.	14 scientists from university or government institutes around the world.	Prepared by staff of the A N Marzeev Research Institute for General and Communal Hygiene, Kiev.
Basis of findings	Review (following stated procedure) by subcommittees of original research data.	Published literature reviews (1993 WHO review) plus other material brought by committee members.	Literature review carried out by ICNIRP members and standing committees.	Unpublished, but appears to be consideration of research literature, combined with technical and economic factors.

Organisation	ANSI*	Standards NZ	ICNIRP**	USSR Ministry of Health
Opportunity for public input	Meetings open to anyone to attend and raise matters for discussion. Released for public comment.	Members representing Australian and NZ public, draft sent out for public comment.	None.	None.
Review processes	Review by other professional organisations (eg Bioelectromagnetics Society) and by ANSI Board.	Reviewed by parent Standards committee.	Worldwide peer review.	Reviewed by USSR Ministry of Health.
Safety factor***	50	50	50	Unknown.
Requirements for acceptance	Open ballot by subcommittees and main committee, attempts made to reconcile negative ballots followed by further vote. At least 75%of members must vote, 75% positive votes required for acceptance.	67%vote in favour, and minimum of 80% of votes received are in favour.	Unanimous approval	Approval from USSR Ministry of Health

* ANSI: American National Standards Institute

** ICNIRP: International Commission on Non-Ionizing Radiation Protection

.† This Standard was originally developed as a joint project between Standards New Zealand and Standards Australia, but was only adopted as a Standard in New Zealand. It is anticipated that the Australian Communications Authority will introduce regulations which are based on this Standard.

*** Safety factor is the amount that the public exposure limit is set below the exposure levels which are considered to be harmful.

Brief notes on these Standards are given below, and a more complete discussion of the background and processes behind them is in Appendix D.

Many of the recent standards, such as those formulated by ICNIRP, ANSI and the New Zealand Standard, are based on the most sensitive adverse effects that can be established. The consensus finding is that these occur at an SAR, averaged over the body, of 4 W/kg. At lower frequencies, where induction of currents is considered the limiting effect, the basis is expressed in terms of current density induced in the body. This does not mean, however, that data suggesting the possibility of effects at lower levels has been ignored. This data, like all the rest, has been evaluated on its merits but not found sufficiently persuasive or convincing to form the basis for limiting exposures.

Although there are differences in detail of the limits set by these bodies, they do have the same underlying basis. Limits for the public are set 50 times lower than the level at which health effects may start to occur. All three standards are revisions of earlier guidance, but there were no significant changes made during the revisions.

Uniquely, the New Zealand Standard also includes a requirement, independent of compliance with the exposure limits, for *minimising, as appropriate, radiofrequency exposure which is unnecessary or incidental to the achievement of service objectives or process requirements, provided that that this can be readily achieved at modest expense*

and

[demonstrating] that installations are planned and operated in accordance with appropriate industry best practice.

Although some Eastern European Standards have set lower limits than those in more recent standards, the reasons for this, and their current status are not entirely clear. There are several major differences between the approach to standard-setting followed in eastern European countries and in recent standards and guidelines from "western" and international bodies:

Table 3 Comparison of eastern and western European standard-setting

Characteristic	**Eastern European**	**Western**
Philosophy	Start as low as technologically possible and may be relaxed on economic grounds or as more knowledge accumulates	Appraisal of the research literature, with safety factors
Exposure/ dosimetric quantity	Single exposure quantity (eg, electric field strength)	Dosimetry and fundamental limits based on power absorbed in the body with limits in terms of electric and magnetic field strengths, and power flux density.
Assessment of research	Any effect assumed to have potential health consequences. Much research based on pulsed sources (eg, radar).	Reported effects assessed in terms of possible health consequences, reproducibility of experimental data given high consideration.

Exposure limits recommended by the four bodies considered in this section are plotted below as a function of frequency, between 1 MHz and 10 GHz. (Note that the limits in the New Zealand Standard are the same as those expressed in the ICNIRP 1998 guidelines.) In order to facilitate comparisons, they have all been expressed in terms of the power flux density, although it should be noted that doing this involves making a few simplifications on the detail given in the actual standards documents. Nevertheless, they still allow for a fair comparison.

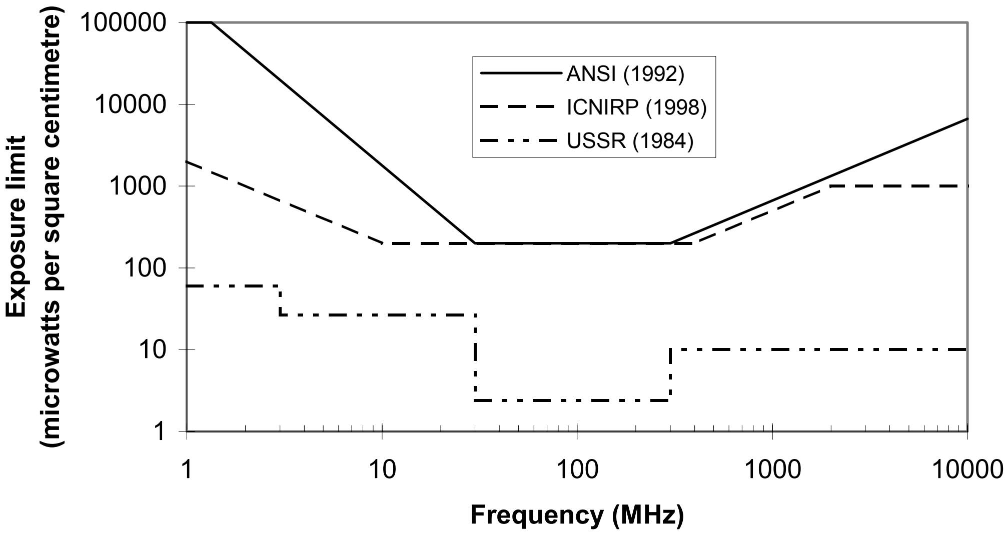

Figure 5. Exposure limits as a function of frequency