BIOLOGICAL EFFECTS OF WEAK RADIOFREQUENCY RADIATION:

ANALYSIS OF SAFETY STANDARDS, PUBLIC PERCEPTIONS AND OTHER ISSUES RELEVANT TO CONTROL OF RADIOFREQUENCY TRANSMISSION FACILITIES.

A document prepared for the Auckland City Council, by

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AUTHOR NOTE

Dr Ivan Beale is Associate Professor in experimental psychology at the University of Auckland. He has 25 years of research and teaching experience in experimental analysis of behaviour and experimental neuropsychology. During the past 5 years he has made a particular study of behavioural effects of non-ionizing radiation, the area on which current radiofrequency exposure standards are based. Dr Beale has taught research courses on behavioural effects of non-ionizing radiation and has delivered papers on this topic at national and international conferences. His current research activities include a large-scale study of behavioural effects of chronic magnetic field exposure in people living near power transmission lines, and analysis of protection standards for non-ionizing radiation.

Dr Beale has played a major role in persuading Government of the need for a New Zealand standard for protection from radiofrequency radiation. He represents the public interest on the Standards Association of New Zealand committee charged with revising the Interim New Zealand Standard. Dr Beale has acted as a resource for members of the public concerned with numerous proposals for transmission facilities throughout New Zealand. He has frequently given evidence at Planning or Resource Consent hearings, as well as assisting others to do so.

SYNOPSIS

The purpose of this document is to provide Auckland City Council with background information necessary for making rational decisions about the regulation of radio frequency transmitters that involve exposure of the public to radiofrequency radiation.

The document describes the nature of electromagnetic radiation, with particular reference to the radio frequency part of the electromagnetic spectrum. The concepts of radiation power and dosage are explained by reference to the effects of radiation on objects placed in the radiation field.

A summary is provided of the literature on biological and health effects of radiofrequency radiation. It is concluded that adverse health effects clearly exist at dosage levels sufficiently high to cause tissue heating, but it is unclear whether biological effects of radiation doses below this level should be regarded as indicating a health risk for humans.

Standards developed for protection of humans from adverse effects of radiofrequency radiation are described and analysed in some detail, with particular focus- on the Interim New Zealand Standard, NZS 6609. It is concluded that NZS 6609 does not provide adequate protection from possible adverse effects indicated by numerous studies showing biological and behavioural effects of radiation doses too low to cause appreciable tissue heating. Revised maximum exposure levels are suggested that do provide such protection. It is noted that the reasons given in existing standards for offering protection from some effects but not others, are based not on science but on implicit value judgements. An argument is made that the public should participate in decisions about the basis for setting of maximum exposure levels.

The standard-setting process and the Resource Consent hearing process are analysed with regard to the restrictions imposed on public participation. Attention is drawn to the primacy of technical judgements and the down-valuing of community attitudes and perceptions as being non-scientific, emotional and value-laden. It is suggested that the public should participate fully in community health issues such as radiation control, both because they can contribute a unique perspective and because they should not be exposed to unacceptable risk.

With regard to cell phone repeater sites, the likely maximum exposure level near a typical site of around 4 microwatts/square centimetre affords a reasonable margin of safety relative to known biological effects of continuous RF/MW fields, including athermal effects of uncertain biological significance. It conforms with adopted standards in all Western and most Eastern European countries. It is considerably lower than existing exposure levels in some residential areas in New Zealand. The 4 microwatts/square centimetre exposure level is nevertheless high relative to average exposure levels found in surveys of large U.S. cities.

PART 1

ELECTROMAGNETIC RADIATION AND ITS BIOLOGICAL EFFECTS

1.1 The nature of electromagnetism.

According to the discipline of physics, there are three fundamental forces in nature: Gravitational, nuclear, and electromagnetic. This document is concerned with the effects of external electromagnetism on living organisms.
Electric fields arise from electric charges at rest, while magnetic fields arise from charges in motion. Acceleration and deceleration of electric charges gives rise to electromagnetic radiation. This radiation takes the form of waves of electric and magnetic energy that move out in space, travelling at the speed of light, 300 million metres per second. Although their speed through space is fixed, these waves vary in frequency. This is to say, if we were to count the number of waves that passed a given point in space during a second, this would give the frequency of the radiation, in waves per second.

Radiation is classified according to its frequency, and the different classes may be arranged along a continuum, called the electromagnetic spectrum (see Figure INTRO.1). At one end of this spectrum is high frequency radiation such as x-rays, cosmic rays and nuclear radiation, and at the other end is low frequency radiation such as AC power, brainwaves, and some atmospheric effects. At the lower end are frequencies less than 1 wave/second, while at the higher end frequencies exceed a billion, million waves/second. Towards the centre of the spectrum is visible light and infrared, while microwave and radiofrequency radiation are just below this.

The higher the frequency, the higher the energy. An important distinction is made between ionizing radiation (frequencies above about 2000 million, million waves/second) and nonionizing radiation (frequencies below this figure). This is because the energy in ionizing radiation is sufficient to knock electrons off molecules, creating free radicals which in living organisms may be directly harmful. The harmful effects of nonionizing radiation are caused by different means, including the heating effect of molecular excitation. The cause of biological effects by exposure to radiation too weak to cause heating are poorly understood at present.

Waves/second is designated Hz, after Hertz, the discoverer of radio waves.
kHz is kilohertz (1000 Hz), MHz is megahertz (1,000,000 Hz), and GHz is gigahertz (1,000,000,000 Hz).

1.2 The nature of radiofrequency radiation.

By convention, the radiofrequency (RF) portion of the electromagnetic spectrum is between 100 kHz and 300 GHz. The region above 300 MHz is usually called Microwaves ~1W). As there is no special biological significance in this distinction, the term RF/MW will be used in this document.

1.2.1 Measuring radiofrequency radiation.

Electric charges moving back and forth at, say, 900 MHz, as an alternating current in a radio transmission antenna, generates electromagnetic fields that radiate out into space from the antenna. The electric field is parallel to the antenna and the magnetic field is in a plane at right angles to the electric field.
Near to the antenna (the near field) the relationship between these fields is complex, but further away (in the far field) there is a fixed relationship between the two so that one can be determined from the other. The oscillating waveform of the electric field is shown schematically in Figure INTRO.2. The viewer must imagine another waveform, corresponding to the magnetic field, sticking out at right angles to the paper. The height (amplitude or strength) of the wave corresponds to the strength of the field. For the electric field, this is measured in Volts/metre, and the magnetic field in Amps/metre. In the far field, though, it is more convenient simply to measure the amount of radiated power. Known as power density, this is usually measured in units of Watts/square metre, but in this document it is more convenient to use the smaller unit of microwatts/square centimetre.

1.2.2 Modulation of radio waves.

The basic continuous radio wave just described, in this case a 900-MHz wave, is referred to as the carrier wave. The amplitude or frequency of this wave can be altered by adding a signal to the carrier, as shown in Figure INTRO.2. Amplitude modulation involves varying the amplitude of the carrier in proportion to variation in the signal. Frequency modulation involves varying the frequency of the carrier to reflect variations in the signal. Another method of introducing a signal into the carrier, pulse modulation, is to turn the carrier on and off so that the carrier is transmitted in pulsed fashion.

<u>Cellphone systems</u> uses frequency modulation to introduce signals into the carrier. Unless a signal is being sent from phone or cell site, only the carrier is transmitted, as a continuous wave. When the signal is sent, it modulates the

frequency of the carrier in brief bursts. FM broadcasting also uses frequency modulation of the carrier to send the voice or music programmes from the transmitting antenna to the radio receiver of the listener. AM radio and TV video signals are transmitted as amplitude modulations of the carrier.

It is necessary to keep these different types of modulation in mind when considering the literature on biological effect of RF/MW) because there is evidence that biological processes are less sensitive to continuous and frequency-modulated waves than they are to amplitude or pulse modulated waves.

1.2.3 Transfer of energy from waves to obstacles.

If an obstacle is placed in the radiation field, the waves may be reflected, absorbed or transmitted through, depending on the conductive properties of the obstacle and the angle and frequency of the incident wave. At RF frequencies, a good conductor, such as a sheet of metal, may reflect most of the radiation. A living organism may reflect a little, but will absorb most of the radiation. The depth of penetration into body tissue depends on the frequency. The energy is absorbed in the form of heat, which is radiated or conducted through the body. It is customary to express the radiation dosage absorbed by the body in terms of power absorbed per unit of body weight. The unit is the Specific Absorption Rate (SAR), measured in Watts/kilogram (W/kg). For a body of particular dimensions, the SAR resulting from radiation at a particular power density will vary according to the frequency of the radiation field. For a typical human adult, energy exchange is highest at frequencies between 30 MHz and 300 MHz[2]. Energy exchange at other RF frequencies, say 900 MHz, is much less efficient.

1.2.4 Sources of radiofrequency radiation.

There is some background RF/MW radiation from the earth, from living organisms, and from extraterrestrial sources. Levels vary according to atmospheric factors and variations in the magnetic properties of the ionosphere, but typically they are extremely small relative to average field levels from human-made devices used for telecommunication or navigational purposes.

Human-made sources include medical applications such as diathermy and magnetic resonance imaging (MRI), industrial applications such as heat sealing, detection applications such as security alarms and radar, and an enormous range of telecommunications devices. Applications in the 300 MHz - 3000 MHz range include specialized radio channels such as police and fire, radio navigation, UHF-TV, microwave ovens, diathermy and food processing, as well as cellular phones.[42]

Many of these applications create fields that are very confined to the immediate vicinity and are of little consequence to the wider environment. Significant exposure of the general public arises mainly from telecommunications, especially radio and TV broadcasting. In fact, the purpose of broadcasting is to reach as many radio or TV receivers as possible. The field strengths required to operate receivers are quite small, but there will necessarily be much larger fields near the transmitter. Cellular phone networks use relatively low-powered transmitters to restrict coverage to a circumscribed locality and thereby enable particular carrier frequencies to be used simultaneously at different cell sites in the same general area. Compared with TV and radio broadcasting, the radiation power levels near cell sites are therefore relatively small. Broadcast transmission antennae are designed to confine the radiation so that it doesn't go in directions where it is not required or not wanted. Antennae are said to have horizontal and vertical radiation patterns; these are descriptions of how the radiation is distributed in the horizontal and vertical planes. Power densities of radiation exposures near transmitting antennae cap be calculated from known values of the power supplied to the antenna and the radiation patterns.

Typical directional broadcasting antennae used by commercial operators are designed to project most of the radiation slightly below the horizontal.
However, because of engineering restrictions, there are usually other angles below the horizontal where the amount of radiation projected is substantially larger than desired. That part of the vertical radiation pattern showing most of the radiation directed horizontally is referred to as the major lobe, and the secondary radiation peaks are referred to as minor lobes, or side lobes. Side lobes can be important factors in the assessment of radiation exposures near transmitters, as they can result in small areas being exposed at significantly higher levels that the general areas around them.

1.3 Biological effects of radiofrequency radiation.

1.3.1 Introduction.

Studies of biological effects of RF/MW exposure began in the 1950s, and by 1990 there were over 10,000 published studies worldwide. There are numerous international scientific journals that publish reports or studies in this area, and several confined only to this area. Dozens of books have been written on the topic, and several reviews have been published which have attempted to analyze and summarise the findings of the enormous body of research[3,41,42]. In 1993 over 30 conferences are planned for the dissemination and discussion of the results of newly completed research on biological effects of electromagnetic fields. This area of research is developing rapidly, and it is generally accepted that there is much more to learn than already is known.

All that will be attempted here is to give a broad indication of the major areas of research on biological effects. This will provide a sufficient context in which to place the following sections concerned with the analysis of the basis of RF/MW exposure standards.

1.3.2 Studies of macromolecules and cell systems.

Studies of biological enzymes, cells and groups of cells, in isolation *(in vitro)* have attempted to isolate the mechanisms of interaction between RF/MW fields and biological systems. Numerous effects have been described, but most are consistent with the view that the heating (thermal) effect of the field is responsible. However, a number of recent studies have demonstrated-effects under conditions that seem to rule out thermal mechanisms. Effects shown include the following:

Changes in cell-membrane permeability to potassium, sodium and calcium.

Changes in composition or behaviour of blood-forming and immunological cells.

Alteration of calcium ion exchange in nerve tissue.

Changes in the firing pattern of neurons.

Changes in levels of cancer-related enzymes.

1.3.3 Studies of living animals.

Studies in which living animals are exposed to RF/MW radiation do not permit the same rigorous control of experimental variables that is possible in *in vitro* studies, but they have the advantage that a whole living organism is being studied, making clearer the possible health significance of any effects that might be found. The majority of studies found effects only under exposure conditions that involved significant heating of the whole animal. Classes of effects reported include the following:

Opacities in the lens of the eye.

Changes in the blood-forming and immune systems.

Changes in the cardiovascular system.

Changes in response of the endocrine system consistent with heat stress.

Changes in neurotransmitter uptake and brainwave patterns.

Changes in adaptive behaviour, including exploratory behaviour and learning.

1.3.4 Laboratory studies of humans.

There are a few studies of controlled exposure of human volunteers for brief periods. These studies have established thresholds for feeling warmth and pain due to RF/MW, and for the peculiar phenomenon of microwave hearing, in which individual pulses of RF/MW are experienced as clicks, buzzes or chirps.

1.3.5 Accidental overexposures of humans.

There have been several surveys and reports of brief exposures to radiation levels above the recommended safety limits. The reported health effects include severe anxiety, hypertension, headache, nausea and fatigue. In one case a pilot inadvertently stood for five minutes in front of an airfighter radar antenna. In addition to physical symptoms such as edema and necrosis of neck muscles, there was evidence of memory loss and extreme sleepiness.

1.3.6 Epidemiological studies of human populations.

There are numerous epidemiological studies of groups of humans who are known to have been exposed, usually in their work, to higher-than-background levels of RF/MW radiation. In these studies, health-related data usually come from medical records, questionnaires completed by the workers, and physical examination. Estimation of actual exposure levels is usually a problem in these retrospective studies, because it has to be estimated from records or calculated from transmitter emission data. There is also a problem locating control groups who are equivalent to the exposed workers with respect to other risk factors. These problems create doubts about the actual levels of exposure that might be responsible for any health effects that may be found, and limit the certainty that health effects are due to radiation exposure rather than to some confounding variable such as work stress or chemical exposure[29,35].

There is nevertheless some indication that chronic exposure may increase the incidence of physical symptoms such as heart disease, cancer, birth abnormalities, pregnancy miscarriage, memory problems and lens opacities. Subjective symptoms include neurasthenia, headache, irritability, sleep loss, and concentration problems.

1.3.7 Conclusions regarding biological effects.

There is clear evidence of a range of biological effects, including effects adverse to the health of exposed animals and humans, resulting from radiation doses at levels high enough to cause tissue heating (the so-called thermal threshold). However, there is disagreement among scientists about whether there is conclusive evidence of adverse effects of doses below this threshold. This issue is analyzed in Part 2, which deals with the basis of standards for RF/MW radiation protection.

PART 2

STANDARDS, REGULATIONS AND GUIDELINES FOR RADIATION EXPOSURE

2.1 Standards for emission, indirect hazard, and exposure.

Standards, regulations and guidelines relevant to RF/MW radiation have been developed for different purposes:

2.1.1 Emission standards control the amount of RF/MW radiation that can be emitted from an appliance. For example there is a standard for microwave ovens that specifies a maximum power flux density of 5 milliwatts per square centimetre at a distance of 5 centimetres from the oven door during operation. Although the intention is to prevent overexposure of the operator, this is an emission standard because it specifies the output of the oven rather than the exposure levels anywhere in the vicinity that might originate from the oven. It is clearly more practical to test an oven at the factory than to test levels near every oven that is installed. Cellphones and cell sites are not controlled by emission standards, but by exposure standards.

2.1.2 Indirect hazard standards are intended to control the possibility that RF/MW radiation might inadvertently trigger hazardous events, such as igniting flammable liquids or gases, or initiating electroexplosive devices such as electric detonators. Responsibility for compliance with these standards usually rests with whoever is responsible for the primarily hazardous substance (the gas or detonators), rather than with the operators of RF/MW transmitters. However, it is notable that power flux densities lower than the maximum permissible levels prescribed in Western exposure standards are capable of inducing electric currents in the leads of detonators sufficient to trigger detonation (see British Standard BS 6657: 1986: Prevention of inadvertent initiation of electro-explosive devices by radiofrequency radiation).

2.1.3 Exposure standards control the strength of the RF/MW field that a human may be exposed to either occupationally (as radiation workers) or as members of the general public. In Western countries such standards are advisory only, usually called standards or guidelines, but have been adopted by some regional or local authorities as a basis for enforceable regulations. In the former Eastern Bloc countries, standards typically were introduced directly as enforceable regulations, state or country-wide. In New Zealand, an Interim Standard was adopted by the Standards Association of New Zealand (SANZ) in 1990. This has advisory status only, but has been used by at least one local authority (Waitakere City Council) as the basis of a bylaw limiting RF/MW exposure within that city. Other local bodies are giving serious consideration to introducing similar bylaws. The Interim New Zealand Standard (NZS 6609) is identical to the 1985 Australian Standard *(AS* 2772-1985), reissued in 1990 as AS 2772-1990. This New Zealand standard was introduced to provide a basis for some interim control while a committee worked on a revision that has yet to be completed.

Exposure standards specify the maximum strengths of RF/MW fields to which persons may be exposed. Usually, these are the strengths of the electric and magnetic fields, from which may be derived the power flux density, a measure of the total power in the electric and magnetic fields. These are generally referred to as maximum exposure levels.

For reasons to do with different rates of energy absorption by humans exposed to different frequencies of radiation, most (but not all) standards specify different maximum exposure levels for different frequencies. In the discussion of standards in this report, the whole RF/MW spectrum is considered, but special reference is made to the 900-Mz range used for cellphone transmissions and the 30-300MHz range used for high-power FM radio and TV broadcasting. The majority of standards also specify different levels for occupational exposure and exposure of the general public (or exposure in uncontrolled environments). <u>Occupational exposure is not dealt with in this report.</u>

2.2 History and variability of standards.

The earliest exposure standards for RF/MW were developed in the late 1950s both in the U.S. and the U.S.S.R. These apparently arose from the increasing use of RADAR devices in the military and industry[3]. The maximum exposure levels permitted in the U.S. standard were hundreds of time higher than those permitted in the U.S.S.R. standard, a pattern that persists, though with some reduced differences, to the present. Figure STAN.1 shows some typical Western and Eastern standards and their dates of introduction since 1980. The power density values shown are the maximum permitted levels for continuous exposure of the public to 900-MHz[25]. Maximum permitted levels for the 30-300MHz range are shown in Figure STAN.2. It is clear that the Western levels are much higher than the Eastern ones. This probably because the Western standards are based on the minimum exposure at which adverse heating effects were found to occur in animal experiments (the thermal threshold), whereas most of the Eastern standards are based on the lowest level at which biological effects were found in animal experiments. The Chinese standard is apparently based on epidemiologic evidence gathered from studies of radiation workers.

It is probably relevant that Eastern animal studies typically have exposed subjects for long periods to relatively low radiation doses, whereas Western studies typically have employed acute exposures to higher doses. However, there are other important differences between the experimental methods used in East and West that also could contribute to producing different views of the effects of weak exposures. The difference in standards between East and West are best seen as resulting both from different data bases and different philosophies of standard setting[10,24,28].

Comparison of Western and Eastern standards has naturally led to concern about the adequacy of the Western standards as a basis for protection from adverse effects. Analysis of the process of Western standard-setting, together with a consideration of current Western evidence on biological effects, indicates that the East-West difference is more a result of different philosophies of standard-setting than of differences in the data bases on biological effects.

2.3 Criticisms of Eastern standards.

Differences in experimental methods and conventions for reporting the- results of studies have led to limited acceptance by Western scientists of studies originating in Eastern Europe and China. For example, Eastern research has been criticised as employing methods that fall short of Western scientific standards for valid and reliable design and instrumentation. Eastern standards have been criticised as having selective application (for example, U.S.S.R. regulations do not apply to military activities) or as being "paper standards only ", meaning that little effort is made to enforce compliance.

There is really no objective basis on which to evaluate the validity of these criticisms. It is understandable that there are such major differences between standards developed by regions having such different cultures and languages. The criticisms reflect value-laden judgements about which science is "best", and seem to overlook the fact that enforcement of Western standards, which are advisory only, is entirely voluntary.

It is understandable that the public have been distrustful of the easy dismissal of Eastern standards by Western "experts", regarding this as an unfair attempt to defend unacceptable exposure limits against embarrassing evidence. At least in the public mind, it is not acceptable to treat Eastern standards as being totally without rational foundation.

2.4 Criticism of use of the thermal threshold as the basis for exposure limits in Western standards.

Because this section is relatively long and detailed, it is begun with a summary of the major points.

2.4.1 Summary

Standards or guidelines for safe exposure of humans to RF/MW radiation have been developed in Western countries by ANSI (American National Standards Institute)[2], IRPA (International Radiation Protection Association)[19], SAA (Standards Association of Australia)[31], and NCRP (National Council for Radiation Protection)[24], amongst others. The maximum exposure levels proposed in these standards are based on an adopted threshold value for exposure level possibly causing adverse effects in humans. In these documents, that threshold has been taken to be represented by a whole-body averaged specific absorption rate (SAR) of 4 W/kg. [The SAR represents the rate at which body tissues absorb energy from the radiation field. It is generally accepted as a useful measure of dose] According to these documents, this threshold value is supported by rational, consensual evaluation of the relevant scientific evidence, which is considered to show that behavioural effects possibly associated with health risks occur at levels greater than 4 W /kg but not at levels below 4 W/kg. This report analyses the rationales given in these documents for the 4 W/kg threshold. Statements used in the documents to support the choice of 4W /kg suggest that this value was chosen initially from a theoretical assumption that the only harmful effects of radiation are thermal in nature, and that SARs smaller than those resulting in human adults from vigorous exercise (about 4W/kg) normally would not result in adverse thermal effects.

Critics of this process of threshold determination for adverse effects have noted that it does not take into account certain lines of evidence. These are:

1. Some animal studies showing possibly adverse behavioural effects of RF/MW exposure at SARs well below 4W/kg.

The rationale for excluding such evidence, where given, is that studies of this type have been inconsistent in showing clear effects, and that there is some ambiguity about whether such effects necessarily indicate health risk. Critics of this rationale say a) the ability of studies to find effects is related to the quality of their methodology - studies using sensitive behavioural measures have shown systematic effects; b) it should not be assumed that health risk is confined to thermal effects; and c) that they question the wisdom of having expert committees set the criteria for defining health risk in the absence of public participation.

2. A large number of laboratory studies of RF/MW exposure of animal and human tissues showing alteration of physiological processes at SARs well below 4W/kg.

Much of this work has been published very recently. However, earlier studies were excluded on the grounds that physiological effects in isolated tissues are difficult to relate to possible health risks in living humans. Critics have pointed out the limitations in applicability of a standard that recognises only those effects that are clearly adverse.

3. Laboratory studies showing effects of RF/MW exposure on tissue physiology and tumour growth under condition that exclude thermal mechanisms.

As with the previous category (2), the significance of such effects for living humans is unclear.

4. A few epidemiologic studies of humans working or living near transmitters} showing possibly adverse effects associated with prolonged exposures to RF/MW radiation at calculated SARs well below 4 W/kg.

Epidemiologic studies were excluded from consideration because findings were inconsistent and because of uncertainty about the magnitude of exposures either of exposed or control groups. In addition, these studies were seen as not providing a basis for determining an exposure threshold for health-related effects. Exclusion on these grounds has been criticised as ignoring evidence that indicates, to the public at least, that prolonged exposure to RF/MW, even at athermal levels, may have adverse health effects.

A consideration of these other lines of evidence, together with an appraisal of apparent weaknesses in the process used to develop a thermal threshold, leads to the view that a rational case can be made for a standard that recognises the need to provide limited protection from some identified athermal effects. Two alternative strategies for achieving this are described.

2.4.2 Frame of reference.

This analysis considers only those guidelines/standards available to the author that have published, in English, information on the rationale underlying determination of safety levels, sufficient for some analysis. The ANSI (1982) standard was the first to choose the 4 W /kg threshold, and particular attention is paid to the stated rationale for this. Subsequent documents essentially have adopted this threshold value, with only minor modification. There has been some variation in the use of additional safety margins between the threshold value and the proposed maximum exposure levels.

The main purpose of this section is to identify antecedents to the determination of the widely accepted 4 W /kg threshold value. In particular:

1. What was the role of theory about the presumed nature of field-tissue interaction?

2. What criteria were used for selecting relevant experimental evidence?

3. On what basis was the decision made whether a given effect could represent a possible health risk to the organism concerned or to humans?

2.4.3 ANSI (1982)

[A revision of this standard was approved in 1992. The thermal threshold was retained as the basis for exposure limits. An additional safety factor of 5 was recommended for "uncontrolled" situations, which would include most situations involving exposure of the public. Essentially, then, the exposure limits for the public (non-occupational) are the same as NCRP (1986).]

1. Role of theory about mechanisms. It is stated (p13, 6.4) that classification and judgement of findings were made without prejudgment of mechanisms underlying effects.

2. Criteria for selecting evidence. The stated criteria are positive data, relevance, reproducibility, and dosimetric quantifiability (p12-13, 6.3).

3. Health risk criteria. It is stated that emphasis was placed on studies that had generated evidence of morbidity or debilitation, chronic or acute, and

that the most sensitive measures of biological effects were found to be based on behaviour. Concerning the determination of a threshold level, there are two clear statements: "The whole-body averaged SARs associated with thresholds of reversible behavioral disruption were found to range narrowly between 4 and 8 W /kg in spite of considerable differences in carrier frequency ... , species .... , and mode of irradiation"
(6.4); and, "There was general agreement that adverse effects of acute exposures are associated with whole-body specific absorption rates (SAR) above 5 W /kg. On the other hand, whole-body SARs below 4 W /kg were not by consensus associated with effects that *demonstrably constitute a hazard.* "(6.5, author's italics).

Considering first the statement in clause 6.4, it seems quite inconsistent with the evidence summarized in Table Al and Figure A3, which refer to several demonstrations of behavioural effects at SARs below 4 W /kg. Other studies published at the time in peer-reviewed journals also show behavioural effects at SARs below 4 W /kg, but are not included in the select list in the ANSI document[11,16,38]. It is unclear why they are not included, since they are included in more recent selective reviews[24,15]. It is possible that some of these studies were not included because they were considered not relevant, and that some studies that were included were not used to determine the threshold because the effects were not considered to be hazardous. Unfortunately, insufficient information is given to allow the reader to evaluate the validity of what was done. As it stands, there are valid interpretations of the evidence of behavioural effects available to the ANSI committee that would place the threshold value well below 4 W /kg. Before these are considered, however, we move to a discussion of the statement on threshold value for health hazard in clause 6.5.

Because no definition is given of what constituted a hazard in the minds of the committee members, the question arises of whether a rational process was followed in the setting of criteria for accepting an effect as hazardous. Of the range of definitions proposed in the literature on health hazards[40], which if any was used here? Later in clause 6.5 it is stated that "(certain effects) were not considered adverse because of the inability of the subcommittee's members to relate them to human health." This statement is more informative about the knowledge and inclinations of the subcommittee members than it is informative about the nature of the effects. It also raises the question of whether the members were in agreement that the effects in question *were not related* to human health, even when they were "(unable) to relate them to human health." This question goes to the core of a central issue about what is the most appropriate frame of reference for developing this type of safety guideline. Fundamental though it is, this issue is not acknowledged anywhere in the ANSI document. Consequently, ANSI gives a spurious impression of a protection guide based solely on scientific evaluation, when in fact there is an implicit and over-riding principle that is value-laden.

A more recent review of behavioural effects of RF/MW exposure (NCRP, 1986) states that the ANSI SAR threshold was based on the criterion of *work-stoppage*. The three rat studies and one monkey study available at the time were studies of acute exposure to fields ranging in frequency from 400 to 2450 MHz, and showed thresholds for reduction of food-motivated behaviour at SARs above 4 W/kg. Whether work-stoppage represents the most-valid behavioral health-risk criterion is debated in a later section. It should be noted in passing, however, that more recent studies of the work-stoppage paradigm have returned thresholds of 2.5 W/kg and 1 W/kg[12,15]

2.4.4 SAA (1985).

This document *(AS2772* - 1985) was reissued with minor alterations in *1990 (AS2772* - 1990). It was adopted in 1990 as the Interim New Zealand Standard NZS 6609.

1. Role of theory about mechanisms. It is recognised in the foreword that thermal mechanisms "seem inadequate" to account for some effects (P4).
   There are no other references to mechanisms that would suggest that the committee's attitude to them played any part in the choice of a threshold value or of exposure limits.

2. Criteria for selecting evidence. The committee did not develop a threshold value *de novo*, but rather adopted the recommendation of ANSI(1982) without modification (A6, p13-14). Deliberation on more recent evidence bearing on threshold value was apparently not attempted.

3. Health risk criteria. In adopting the ANSI recommendation of 4 W/kg, the health risk criteria used by ANSI were implicitly accepted. In

addition, however, the committee adopted the ALARA principle, which recommends "that the level of all electromagnetic fields should be kept as low as reasonably achievable" (p5). The adoption of ALARA seemingly is inconsistent with the recognition of a threshold SAR for health risk and conveys the impression of lack of confidence in the adopted threshold value on the part of the *SAA* committee. The reason given for including ALARA is that "the effects of (chronic, non-occupational) exposure are only imperfectly understood" *(SAA*, 1990, clause 6, p9).

As is the case with the ANSI document, there is no explicit statement of a philosophy of health protection or other metaprinciple which would clarify the frame of reference in which the committee were developing their protection standard. The recommendation in the *SAA* standard of both maximum permitted exposure levels and ALARA seems to be a direct result of this.

2.4.5 NCRP (1986)

1. Role of theory about mechanisms. Although mechanisms of field-tissue interaction are extensively discussed in this document, there is no suggestion that assumptions about possible mechanisms played any role in the development of an SAR threshold value (17.3).

2. Criteria for selecting evidence. Efforts were made to include all available peer-reviewed studies published before May, 1982.

3. Health risk criteria. The report is informative regarding the basis of development of the SAR exposure criterion:

   "The body of scientific knowledge of biological effects of RFEM irradiation, although containing several thousands of archival reports, is fragmented: it is preponderantly based on acute exposures at relatively few frequencies. Ideally, exposure-control guidelines would also be based on a well-documented literature that reflects the chronic irradiation of a variety of species across a wide spectrum of frequencies. In spite of the shortcomings of the data, it is necessary to proceed prudently with the process of exposure control through the setting of standards, while exercising appropriate caution and fully informing the worker and the public of the limits of knowledge. " ...

"The most important and directly useful data for the establishment of criteria for limited exposure to any noxious environment are, of course, measurements and findings based directly on human beings. Unfortunately, data of this type, which are epidemiological or clinical in nature, are relatively few in number."...

"In the absence of human data, it is necessary to turn to data on subhuman species in full realization that body dimensions and mass have enormous controlling influence on the SAR at a given frequency. It is also necessary to realize that direct extrapolation of subhuman data to man is also fraught with problems because of specific anatomical, physiological, and biochemical differences among species.
In the frequency range of primary interest, i.e., 30 to 300 MHz, and also at higher frequencies in the microwave bands, a review of the data ... indicates that behavioral disruption appears to be the most statistically significant end point that occurs at the lowest observed SAR" (17.3, p278-279).

The review of behavioural effects concludes as follows:

"Several conclusions regarding the behavioral response to RFEM [radiofrequency electromagnetic] irradiation can be draw that enjoy a substantial consensus among scientists of many disciplines:

1. Behavior not only provides a highly sensitive index of field-body interactions, but a broad spectrum of end points. A single pulse of RFEM energy can be heard by human beings and experimental animals .... The threshold of convulsive activity, which anchors the near-lethal side of the behavioral spectrum, requires absorption of energy six orders of magnitude greater.
2. Lying between the extremes of auditory-perception and convulsive thresholds are intermediate end points of threshold sensitivity that include detection of cutaneous warming, field-drug interactions, endurance, impaired performance, and work stoppage. It is within this intermediate range of end points that consensus is lost and

> controversy begins. At least for acute exposures, the problem lies not in the stability of thresholds .... but in the interpretation of the implications of an altered behavior. Perception of warmth is an effect, but is it indicative of insult or injury? Enhancement of the pharmacologic activity of a drug is an effect, but is it evidence of facilitation or debilitation? The behavioral incapacitation that is reflected in the work stoppage end point could be an indicant of harm, but where below this threshold does a body of scientific or medical experts draw a definitive line for permissible levels of irradiation? That is a question that cannot be answered solely in the behavioral laboratory; only a concerted and integrated effort involving researchers of many disciplines - and many experiments yet to be performed - can provide answers that will summon an unimpeachable consensus." (12.8, p189-I90).

These precautions notwithstanding, NCRP accepted work-stoppage as the behavioural effect with the lowest threshold SAR, that could by consensus be accepted as representing a health risk:

> "Thresholds of disruption of primate behavior were invariably above 3 to 4 W /kg, that latter of which has been taken in this report, as well as by ANSI, as the working threshold for untoward effects in human beings in the frequency range from 3 MHz to 100 GHz." (17.3, p279).

The health risk criterion adopted by NCRP is based, then, on the work-stoppage paradigm, using data from monkeys acutely exposed to frequencies above 400 MHz. The lower thresholds obtained for non-primates were presumably regarded as less generalizable to humans on the basis of size differences (PI83), although this is not explicit. Data set aside by this decision include those from several experiments on effects on activity levels of *chronic exposure* of rats (p186-197), avoidance of exposure by rats (P180) and drug-field interactions (P189), all showing effects at threshold levels below 4 W /kg. The relevance of these other behavioural paradigms to decisions about health risk are discussed in a later section.

It is remarkable that a special safety margin is allowed for occupational exposure where a carrier frequency is modulated at a depth of 50 % or greater at frequencies between 3 and 100 Hz. "It is not known whether these effects pose a risk to health, but their reliability and their independent confirmation in avian and mammalian species dictate a need for caution." (p285-286).

2.4.6 IRPA (1988).

1. Role of theory about mechanisms. Theories of mechanisms of interaction are discussed and it is stated that both thermal and non-thermal mechanisms must be considered in establishing exposure limits (p 120). However, non-thermal effects are later ruled out of consideration (P122) and the guideline states that the exposure limits protect *against thermal hazards*. (author's italics).

2. Criteria for selecting evidence. It is first stated that the recommended exposure limits are based on the detailed review and evaluation of the scientific literature published by WHO (1981). However, extensive reference is then made to ANSI (1982) as a basis for adopting the 4 W /kg threshold. Reference is also made to some more recent reviews[15,24].

3. Health risk criteria. ANSI is cited as having found behaviour in experimental animals to be the most sensitive indicator of an adverse health effect, listing as examples convulsion activity, work stoppage, work decrement, decreased endurance, perception of the exposing field and aversion behavior (P121). This is presumably in error, as the ANSI document does not treat field perception or aversion as adverse effects.

Evidence of untoward effects at SARs below 4 W /kg is recognised (p122) but not seen as indicating a need to reduce the threshold below 4 W/kg. Data on possible non-thermal effects, drug-field interactions, RF/MW potentiation of chemical toxins, and ELF-modulated RF/MW fields were considered "insufficient to make either a health risk assessment of even to determine if these effects present a potential health concern." (P122).

Although the stated objective of the guidelines is "to protect human health from the potentially harmful effects of exposure to radiofrequency electromagnetic radiation" (P 119), the strategy for achieving this is nowhere made explicit. In the section headed "PURPOSE AND SCOPE"

(P116) an attempt is made to declare disconnected sentences that follows contradictory: a position, but the series of can seem somewhat self-contradictory:

> "The committee recognized that when standards on exposure limits are established, various value judgements are made. The validity of scientific reports has to be considered, and extrapolations from animal experiments to effects on humans have to be made. Cost- versus-benefit analyses are necessary, including the economic impact of controls. The limits in these guidelines were based on the scientific data, and no consideration was given to economic impact or other nonscientific priorities. However, from presently available knowledge, the limits should provide a safe, healthy working or living environment from exposure to RF/MW radiation under all normal conditions."

The first sentence raises the question of who is making the value judgements (the committee, or others?). If the committee, what are these judgements? What is a "nonscientific priority"? Is it different from a value judgement? All that this paragraph makes clear is that the committee either had no concept of the metaframework in which they developed the guideline, or they don't wish to declare it.

Finally, it is noted that IRPA, while recommending maximum exposure levels, also recommend an additional precaution, that "In view of our limited knowledge on thresholds for all biological effects, unnecessary exposure should be minimized." (p 118). This requirement is similar in intent to the ALARA principle included in *SAA* (1985).

2.4.7 General discussion.

The foregoing commentary on the various exposure standards makes clear that all derive health risk thresholds directly from those developed for ANSI (1982). Information given in the ANSI document and in the NCRP document indicates that the 4 W /kg threshold value is based primarily on primate studies using the work-stoppage paradigm. This paradigm has been taken as a valid index of an adverse health effect applicable to humans. Lower thresholds obtained using the same paradigm with small non-primates, as well as lower thresholds obtained with other behavioural paradigms such as avoidance, activity, and drug-field interactions, have not been taken to indicate the need for a lower threshold. The reasons for setting aside these data from providing a basis for a health risk threshold are not given in the ANSI document. Possible reasons are: that the experiments were not methodologically sound; that they could be given little weight because they used small non-primates, and this would seriously limit the generalizability to humans; or, the paradigms did not demonstrate clearly an adverse health effect.

With respect to methodological soundness, several of the relevant studies were published in reputable international scientific journals and had been subjected to peer review as part of the normal editorial process. Some appear in the list of selected studies meeting the ANSI criteria. On the related matter of replicability, this appears to be achieved to much the same extent in the studies of, for example, activity level effects in rats, as in work-stoppage in primates.
It is not *direct* replication that is required, since this can only be achieved within a particular laboratory, but *systematic* replication with variation in relevant task parameters[34].

On the issue of whether it is advisable to generalize from non-primate studies to humans, much depends on the nature of the effect being measured and the biological and behavioural systems that underlie it. At the level of gross physical dimensions and thermoregulatory mechanisms, both relevant to thermal considerations, large monkeys and humans have much in common. However, unless it is established that the behavioural effect of interest has a thermal basis, it cannot validly be assumed that there will be better generalization to humans from monkeys than from non-primates.

The foregoing discussion of health risk criteria in the four standards strongly indicates that studies finding thresholds below 4 W/kg were set aside primarily because the effects were not regarded as an adverse health effect. Nowhere is an explanation given of the basis on which this judgement was made, although the impossibility of making this judgement on objective grounds is explicated at length in the above quotation from NCRP (1986). The effect adopted as adverse, work-stoppage, is a behavioural effect, as are the rejected effects of activity change, stimulus control (discriminative capacity), drug-field interaction (dose-response function), and field avoidance. The interpretation of all of these effects as indicators of adverse conditions for the animals concerned, is as complex as it is controversial among behavioural scientists. Although the issue has been explored for decades in extensive theoretical and empirical work, there is no clear way to demonstrate whether a particular behavioural paradigm can be used to identify an environmental event as adverse for the organism concerned. The issue has recently been given prominence internationally by the animal welfare movement and by scientists and philosophers engaged in the study of animal ethics. A recent issue of *The Behavioral and Brain Sciences* (March, 1990) included a special section on the problem, in which there was a free exchange of views among behavioural scientists and ethicists with different perspectives. It is clear from this that behavioural scientists take seriously the idea that paradigms like aversion behaviour and activity suppression might indicate adverse states. The identification of human adversity raises problems that are no less complex, despite the ability of humans to say what they do and don't like, especially if the attitude is taken that humans are not valid judges of what is good or bad for them.

The relevant current behavioural literature indicates that there is no scientific basis to support ANSI's decision to regard activity change, reduced learning, etc., as not adverse to the health of the animals concerned. Behavioural disadvantage might be more costly to animal welfare even than direct tissue damage, depending on the behavioural economics of the animal's environment. From a behavioural scientist's point of view, there seems to be no scientific basis for accepting the work-stoppage paradigms as indicating an adverse effect, but not extending the same interpretation to, for example, avoidance of fields or loss of ability to learn. The cause of work-stoppage in the RF/MW exposure studies is quite possibly not the direct effect of an aversive stimulus or even an indirect effect of RF/MW heating, but interference with the control of behaviour by the same mechanism responsible for other behavioural effects of radiation[4].

Work-stoppage has no claim to special status as a behavioural effect, though it appeared to have carried weight with the ANSI committee because there is a clear correlation with increase in body temperature[12].

2.4.8 Behavioural effects at SARs below 4 W/kg.

A rational case can be made for taking into account behavioural effects other than work stoppage in determining safe exposure levels. Several studies have found activity changes in rats at SARs around 1 W /kg[11,23], and in one study doses as low as 0.2 W/kg were found to produce avoidance in rats[16]. In that study, the free choice procedure used permitted the measurement of the relative preference between exposed and unexposed enclosures. Given that the preferred, unexposed enclosure was not attractive for any other reason, the exposed enclosure therefore must have had some relatively aversive property[18]. Another series of studies demonstrated that RF/MW exposure at SARs at least as low as 0.2 W/kg caused a significant change in the effects of a stimulant drug on rats performing a lever-pressing task[38]. Similar studies in other laboratories have since confirmed this result and extended it to other drugs[20].

These effects could represent an adverse effect in humans, because the drugs involved are widely used for the treatment of a range of behaviour and learning problems in children and adults[1].

It is important to note that these behavioural studies used RF fields that were pulse modulated at low frequencies, that is, turned on and off many times per second. This is because it is well established that pulsed fields more readily affect biological processes than do continuous fields of the same power density.

Many experiments that have compared the ability of the two types of field to affect physiological processes have shown the continuous field to be relatively inert.

It is accepted that these effects do not prove an adverse effect for humans (or for rats) at these lower SAR values, any more than the work-stoppage demonstrations prove it at 4 W/kg. What can be said, however, is that they are credible indications of a possible adverse effect in humans exposed to comparable conditions.

2.4.9 Physiological effects at SARs below 4 W /kg.

The behavioural effects discussed above have particular significance because they occur in living, behaving organisms and are therefore readily interpretable with respect to health risk in humans. On the other hand, there are numerous laboratory studies, in which animal or human cells *in vitro* have been changed by exposure to RF/MW fields at low SARs, where the significance of the effect for living humans is quite unknown. Examples of such effects include bursts of firing of isolated neurons[6], enhanced lymphocyte transformation and membrane changes in neuroblastoma cells[13,14]. Such effects are typically reported at SARs as low as 0.2 W/kg and at a range of frequencies including some in the band used for cellphone transmissions (approx. 900 MHz). Once again, though, it is notable that many such effects typically are obtained only if the field is pulsed or amplitude modulated at low frequencies. Although continuous fields have been found ineffective in many studies, there are nevertheless a group of very recent studies in which continuous fields have been reported to cause a variety of physiological changes. For example, DNA synthesis of specific genes[14], transcription rate of specific genes[39] and blood-brain barrier permeability[32] have all been shown to be altered by 915 MHz continuous-wave radiation at SARs around 0.1 W/kg. Certain consistent findings, from studies in which neural physiology of living animals is affected by brief exposure to RF /MW continuous or pulsed fields at SARs less than 1 W/kg, has led researchers to suggest that such low level radiation is a "stressor"[20]. However, at this stage there is no convincing evidence that such changes lead to adverse effects that are irreversible.

The most widely replicated physiological effect of weak RF exposure of human or animal cells demonstrates that the release of positive calcium ions from the cell membrane is systematically related to both the strength of the field and the frequency at which it is amplitude modulated. The effect has been shown to occur at SARs between 0.02 W/kg and 0.05 W/kg, but only when the field is amplitude modulated at frequencies below 100 Hz[26]. It is notable that the field strengths involved are about 100 times less than the threshold for adverse effects set in Western standards. If these effects should prove to have adverse consequences in humans, there is clearly no protection offered in those standards.

Figure SAR.l shows the dosage levels associated with the effects described above. Figures SAR.2a and SAR.2b show the derived exposure levels at 900 MHz and 30-300 MHz, together with some recommended maximum exposure limits. These figures permit a visual evaluation of the safety margins between known effects and recommended maximum exposure levels.

2.4.10 What is a health risk and what isn't?

The acceptance or rejection of these effects as adverse by any human is not a matter for scientific judgement; it is a value judgement based on things such as cost/benefit analysis, perception of personal and social responsibility, information, and point of view[36]. Not least among these influences is the individual's assessment of the likelihood that she or he personally might be affected. When committees are empowered to make such judgements on behalf of the population at large, the personal ideology and ethics of each member has a fundamental influence on the outcome of their deliberations.

It cannot be emphasized too strongly that scientists or technologists have no particular expertise relevant to such judgements. Indeed, their expert knowledge and training may introduce biases in their thinking quite inappropriate to the type of decision at hand. Many scientists dread being considered credulous or soft-minded by their peers. To accept the likelihood of a new effect which is later discredited is to get egg on your face[21]. The ensuing scepticism is not without value in science, but may provide an inappropriate set for judgement in the arena of health risk assessment. At least in the minds of potential victims, adequate health protection requires a willingness to recognize potential health risks as early as possible rather than a determination to deny them as long as possible. The experience of asbestos and ionizing radiation provides an instructive example of just how costly the wrong attitude can be[33].

2.4.11 Safety margins in standards: Do they accommodate athermal effects?

Even were it accepted that there was sufficient evidence of possible adverse effects at SARs as low as 0.2 W/kg, it may nevertheless be thought unnecessary to revise recommended maximum permitted exposure levels, on the possible ground that effects found at SARs below 4 W /kg are provided for by the safety margins included in the standards, which typically set maximum exposure levels for the general public 50 *times* lower than the exposures required for SARs of 4 W/kg. Many scientists consider that athermal effects are well-accommodated by this margin. However, this argument has been criticized on the grounds both of the size of the margins and the reason given for having them. These are listed in Table 1 below.

STANDARD	MARGINS	REASONS GIVEN FOR MARGIN
ANSI(1982)	1. Occupational, 10 2. Public, 10	Allow for possible 8-hr/day exposure of workers, possible higher temperature and humidity, generalization from animal to human.
SAA(1985)	1. Occupational, 10 2. Public, 50	l. Same as ANSI(1982). 2. Greater variation in size, physique and age, compared to workers.
NCRP(1986)	1. Occupational, 10 2. Public, 50	l. Same as ANSI(1982). 2. Public less informed of risks, less able to control their exposure, contains vulnerable persons (aged, infant, ill, pregnant), larger numbers, continuous exposure.
IRPA(l988)	1. Occupational, 10 2. Public, 50	1. Same as ANSI(l982). 2. Same as NCRP.

Table 1. The four standards, adopted safety margins, and reasons given for the margins.

It is clear that the safety margins were not stated as providing for unknown or unrecognized adverse effects at SARs lower than 4 W/kg. To preserve the same margins for the factors allowed for, relative to an effect at 0.2 W/kg, the new maximum permitted exposure levels would need to be 20 *times* lower than those based on the 4 W/kg threshold. In the frequency range transmitted from cell sites (around 900 MHz) the limit for the general public would be 30 microwatts/square centimetre. In the 30-300 MHz range the limit would be 10 microwatts/square centimetre (see Figure STAN.3).

It is argued that current Western safety standards provide adequate protection from thermal effects only. There is insufficient evidence for any particular threshold for athermal effects or any particular safety margin; it is a question of where best to set the criterion for acceptable exposure. Under these circumstances, and guided by the ethical principle of informed consent, there is a strong argument that the maximum permitted exposure levels should be as low as is achievable without undue loss of any benefits that might accompany exposure.

At first thought, it may seem possible that a committee could set about the task of developing guidelines within a frame of reference that only included criteria that were wholly objective. Ideally, this committee might produce a consensus decision that above a certain exposure level there was a significant risk of an adverse effect while below this level there was not. Such an objectively derived standard could then be used by regulating authorities who could introduce additional safety margins according to their own philosophy of health protection. It may be that some of the committees responsible for the standards reviewed above thought that they were doing just this. Clearly, they were not, because even the most cursory analysis of the concepts of health risk or adverse effect shows that these concepts are value-laden. So far as can be gleaned from the published rationales for these standards, there was no serious attempt to address the ethical aspects of health protection. Only IRPA has any comment on the issue, and this can only be regarded as naive. It is clear that the decision process underlying the adoption of the 4 W/kg threshold and the additional safety margins did not involve only objective criteria and rational argument; these were embedded in over-riding, unacknowledged assumptions about health risk and adversity which are, to say the least, questionable.

2.4.12 Should there be separate standards for pulsed and continuous fields?

At first glance, the predominant finding that pulsed or amplitude modulated fields are generally more biologically significant than are continuous or frequency modulated fields, might suggest that it is practicable to set a more restrictive standard (i.e., lower maximum permissible exposure levels) for pulsed fields. In fact, some Eastern standards have done just this. However, such a strategy is inconsistent with the recent findings that continuous fields, as weak as 0.1 W/kg, may be just as effective as pulsed fields in eliciting some classes of physiological change. In particular, it would be premature to assume that reliable effects at SARs below 4 W/kg were confined to pulsed or amplitude modulated fields.

2.4.13 Is there sufficient evidence to establish thresholds for athermal effects?

There is not sufficient evidence to establish exposure thresholds for athermal effects, nor even to establish whether thresholds exist. It is not difficult to understand why some standards committees have chosen to confine their deliberations to thermal effects, where the basis for determining a threshold seemed relatively clear. Not only are athermal effects difficult to interpret in relation to possible adverse effects in living humans, but the complexity of having to consider differential effects of wavelength, waveform and field strength seems daunting, to say the least. In particular, the studies of calcium release from the cell membrane seem to deny the possibility of any simple dose-response relationship, since there is ample evidence that such effects occur in specific windows of both frequency and amplitude of field. In some studies, smaller field amplitudes have yielded larger effects. In any case, thresholds established in laboratory studies with animal tissues are not readily generalized to living humans. Nevertheless, the possibility remains that there is a linear, or other simple relation, between some adverse athermal effects and radiation dose, whether or not a threshold exists below which the effects do not occur. There is just too little evidence at present to indicate one way or the other.

2.4.14 Can rational exposure limits be set that protect against athermal effects?

There are alternative strategies that could be used to reduce the likelihood that human exposures might cause athermal effects comparable to those observed in animals and human tissues. One simple strategy would be to take the lowest dose boundary at which significant athermal effects have been reported for a given type of field (continuous or pulsed), then use a suitable safety margin below this to determine maximum permissible exposures. The rationale is the same as that used for thermal standards, except that limits are not based on known thresholds. Application of this strategy would yield an exposure limit for the general public, for continuous fields, of 30 microwatts/square centimetre at 900 MHz and 10 microwatts/square centimetre at 30-300 MHz. Figure STAN.3 shows the resulting athermal standard in terms of a function relating radiation frequency to maximum permitted exposure, across the full RF/MW spectrum. Also shown is the thermal standard AS 2772 (NZS 6609) for non-occupational exposure.

Setting aside the obvious issue of whether athermal effects represent adverse effects in humans, the usual criticism of this approach is that while it intends to provide protection from athermal effects, it clearly might not do so, because it is based on very incomplete knowledge of the nature of these effects. It might therefore require frequent revision as knowledge increases. However, proponents of this strategy have argued that frequent revision is healthy and that however imperfect the athermal standard might be, it nevertheless provides some degree of protection from some classes of effects, which is better that none at all.

A second strategy that has been advocated is to establish a dose level at which no effects have been reported reliably, and set the maximum exposure level as close to this as is economically feasible (See Appendix 1). The advantage of this strategy is that it recognises explicitly the inability to guarantee protection from poorly understood athermal effects, yet also recognises the need to offer protection beyond that provided by thermal standards. A major disadvantage is that it places the process of setting exposure levels almost entirely into the bargaining context, where the interested parties would have to grapple with the relativities of perceived health risks for individuals or communities versus dollar costs for the telecommunications industry. It is not a standard so much as a negotiated agreement.

2.5.1 The Interim New Zealand Standard.

Development of a New Zealand standard was initiated by the Minister of Broadcasting in the last Labour government in response to public and local authority concern over radiation levels near the Waiatarua transmitter site in the Waitakere ranges. A committee was appointed by the Standards Association of New Zealand (SANZ) in February, 1990, to develop a standard for maximum exposure levels for radiofrequency radiation. At the third meeting of this committee, in July, 1990, it was resolved to adopt the 1985 Australian Standard as an Interim New Zealand Standard while the committee continued to work on a revision that would be more acceptable. The maximum permissible exposure levels for the public (0-24hrs/day) are shown in Figure STAN.3. The committee recognised many problems with the Australian Standard that it intended to address in the revision. However, the task of revision had yet to be completed when in July, 1992 the committee was disbanded after SANZ decided that a joint standard would be developed by a joint Australia/New Zealand committee. By January, 1993, no progress had been made on appointing ajoint committee to work on a new standard. In light of the usual rate of progress in these matters, it is probable that the Interim standard (NZS 6609) will not be superseded for several years.

In the meantime, the interim standard generally will be used as the primary basis for regulation by local and national authorities and as a basis for engineering decisions by the telecommunications industry. Although this might seem a convenient arrangement, it is not without problems.

2.5.2 Problems with the Interim New Zealand Standard.

2.5.2.1 General problems.

1. Essentially, this is a thermal standard, and therefore is not designed to provide protection from athermal effects. However, it is notable that the maximum exposure levels specified for frequencies above 300 MHz include an additional safety factor relative to other major Western standards. Since the adoption of this standard in Australia (1985), a large number of Western studies have reported athermal effects, strengthening arguments that such effects cannot justifiably be ignored.

2. Several commentaries on the development of the Australian standard, of which the New Zealand standard is simply a reiteration, have been critical of the lack of representation by community and environmental interest groups. In particular, there lacks any element of informed consent by representatives of the public who are potentially exposed to adverse effects of radiation (Appendix 2).

3. Although the code of the standard states that the ALARA principle should be followed, it does not state how this should be applied alongside the prescribed maximum exposure limits. This ambiguity has led to the ALARA principle being ignored in tests for compliance with the standard.

4. The code is ambiguous with respect to the assignment of responsibility between operators in locations where multiple operators contribute significantly

to the total exposure levels.

5. The code is not sufficiently explicit regarding the procedure for measuring partial body exposures during compliance testing.

6. No explicit procedures are laid down for testing compliance with the specified maximum exposure levels for the general public.

7. There are other technical problems with the standard that have been detailed elsewhere (See appendix 3).

2.5.2.2 Problems particularly relevant to transmitters using frequencies above 300 MHz.

The standard specifies that when measurements are made close to a radiating source (the distance depends on frequency and antenna dimensions) the electric and magnetic fields which make up the electromagnetic radiation must be measured separately. This creates a problem, however, because the broadband field probes normally required for measuring exposures are at present not capable of accurate measurement of magnetic fields at frequencies above 300 MHz.

2.5.3 Revision of the Interim New Zealand Standard.

As noted above, the standard is now to be revised by a joint Australia/New Zealand committee. Prior to the decision to develop a joint standard, announced in June, 1992, both the Australian and New Zealand committees had already spent some time considering what revisions might be made. Both committees have received submissions from committee members and the public on this issue. Some of these submissions recommended increasing maximum permissible exposure levels for some frequency ranges, but the majority recommended reductions by factors ranging from 20 to 200. A dominant theme in the submissions is that there should be strong public representation on the committee, and that strong weighting should be given to the public viewpoint during the standard-setting process (see Appendix 1, 2).

The inclusion of adequate public representation on the joint committee is now a strong possibility, if only because of a general appreciation that this is a necessary condition for the new standard to gain public acceptability. The likely result of such representation is a downward revision of maximum exposure levels for the general public. The magnitude of that revision will be mainly a matter for negotiation between the representatives of public and industry. Current indications are that the industry, especially in Australia, would incur substantial costs if the maximum exposure levels were reduced by a factor greater than 4 (50 microwatts/square centimetre for frequencies above 30 MHz). According to industry representatives, exposures near this level already exist in populated areas near many radio transmission masts in Australia. It therefore can be expected that the industry would strongly resist any moves to reduce maximum levels to less than half current values.

There is considerable public awareness of athermal effects and there is resulting pressure to require standards to recognise them. This recently has been reinforced by publicity about several recent studies showing an association between weak 50-Hz and 60-Hz magnetic field exposure and excess risk of childhood leukemia. In particular, the public have learned of the huge gap between existing advisory standards for low-frequency magnetic-field exposure (1000 milligauss) and the much lower levels associated with leukemia (2.5 milligauss). This has seriously undermined any faith the public may have had in current standards for nonionizing electromagnetic fields. It provides a clear example of the weakness of basing standards solely on known hazards with known mechanisms.

In this climate, it seems unlikely that any members of the joint Australia/New Zealand committee who are so disposed, will be able to hold out against the pressure to lower exposure limits. Although they could elect to stall progress indefinitely, and thereby enjoy the continuation of the status quo, it seems more likely that agreement would be reached at a level that gave something to all parties. Probably, that would be a reduction of maximum exposure levels by a factor no smaller than two and no greater than four. While no-one would find this satisfying, all parties could probably live with it. Of all the possible outcomes, this therefore seems the most likely.

PART 3

ACCEPTABILITY ISSUES NOT RECOGNISED IN EXPOSURE STANDARDS

3.1 Introduction.

The absence of participatory involvement of the public in the standard-setting process has limited severely the acceptability of the standards by sections of the public. Among the reasons for this are the following: The public have been denied the opportunity to receive and consider accurate information; they have not been given the opportunity to present their own attitudes and perceptions on hazards and risks; they have been denied a constructive role in a genuinely consensual process leading to a standard in which they could feel they had played a significant role. On this theme of acceptability, experts on the assessment of environmental contaminants have identified several relevant psychological issues[5,27,30]. These are briefly considered below.

3.2 Public perceptions of risk.

Although the general public often lacks credible information about possible hazards such as nonionizing radiation, its basic conceptualization of risk may be richer than that of experts in the field and reflects perspectives and legitimate concerns that typically are omitted from expert risk assessments. This is especially the case where communities have experienced exposure to unwanted contaminants that represent an unknown risk. Risk perception studies have shown that expert and public perceptions of hazards are very different, leading to dispute about acceptable methods for regulation or control. It has been noted that "Risk management efforts are destined to fail unless they are structured as a two-way process. Each side, expert and public, has something valid to contribute. Each side must respect the insights and intelligence of the other."[27]

3.3 Anxiety, stress and perceived risk.

The sociological and ecobehavioural models of health recognise that health has many dimensions and outcomes which may be affected even in situations where there may be no significant exposure to environmental contaminants such as radiation. Perceived exposure may be as effective as actual exposure in generating anxiety and stress, both of which are measurable in terms of adverse physiological changes in biological systems such as the immune and nervous systems. Lack of access to credible information has itself been shown to cause stress. This reinforces the importance of public involvement in the standard-setting process and it underlines the need for sharing of the power and responsibility for decision-making leading to the standard[27]. Where this does not happen, as has been the case with RF/MW standards, it is inevitable that public concern and anxiety will be expressed in distrust of, and opposition to, the standard. This legitimate response will then have to be accommodated at the level of public outcry, litigation and regulatory processes such as resource consent hearings.

3.4 Environmental ethics and informed consent.

Sharing of environmental resources, including free space, is subject not only to rules and regulations, but also to ethics principles. A commonly recognised principle is that the activities of one individual or organisation should not unreasonably impact on others without their informed consent. It seems to be a common view, even of health professionals, that informed consent cannot be applied to issues such as the possible adverse effects of weak RF/MW exposures, because adverse effects are not proven, because any risks would be much smaller than the risks routinely accepted by most people in the course of everyday activities (crossing a road, etc), and because the exposures are associated with substantial benefits for the wider community. Although this view would not be shared by those persons subject to higher than normal exposures, it *is* not only a matter of differences in perspective.

First of all, it is arguable that persons should not be exposed to unacceptable risk, regardless of why they find it unacceptable. The fact that experts cannot agree that the evidence indicates a clear risk should not be taken to mean that the risk does not exist[30]. Under these circumstances there is a case to be made for playing it safe by setting maximum exposure levels as low as is technically feasible. This is the preferred strategy of members of the public, especially those subjected to higher-than-average exposures. Secondly, no-one can be certain that the risks from low exposures will necessarily be small, and in any case those being asked to bear the risks are not just those who stand to benefit from the industrial use of RF/MW. That fact that persons are prepared to accept some risks in the interest of gain or convenience to themselves, does not mean that they should accept smaller risks others might expose them to for the convenience of profit of those others. Finally, even if the benefits of higher radiation exposures may be said to devolve to the community in general (e.g., better or cheaper telephone services) it does not follow that the costs should be borne by the few unfortunate individuals who consequently will be subject to higher exposures. Environmental health experts increasingly take the view that the public should be informed as fully as possible about the nature of any possible risk, however uncertain it may be, and helped to make their personal decision about whether they are willing to be exposed.

It is useful to contrast this recommendation with the strategy underlying current Western exposure standards. Here the practice is to determine the threshold for a clearly adverse effect, then take an arbitrary safety margin below this to get maximum exposure levels. All the important decisions are taken by the radiation experts and the representatives of commercial and military users. Public perceptions, opinions and attitudes, have no place in this process. When, eventually, the public have their say, it is likely to be characterized as ill-informed, emotional, value-ridden and selfish; while the standards are held out to be value-free, scientifically derived, rational, and so on.

3.5 Prudent avoidance: Public and operator responsibilities.

Light and heat apart, most personal electromagnetic field exposures are from extremely-law-frequency (ELF) fields associated with electric appliances and cabling at home and in the workplace. Recent concerns about the association between ELF and cancer have led to a suggested remedial measure called "Prudent Avoidance". Basically, this means taking whatever precautions will reduce exposure without costing much. The principle is readily applied to ELF exposure because most individuals have control over many of the more significant ELF sources in their lives. They can often get significant reductions by moving a clock radio further from the bed, turning off the electric blanket before retiring, sitting well back from their computer, and so on, all at no cost.
In some cases, though, these exposures may be small relative to some uncontrollable source such as a nearby transmission line. Then, significant reduction may not be achieved without the help of the operator of the transmission line, and the cost of any change may be large. Moreover, the operator may see the cost (to the operator) of any changes as being huge in relation to any dubious risk reduction (for the individual) that would result.

Unlike ELF, there are few sources of significant levels of RF/MW radiation exposure for the public, other than those controlled by the industry. There are regulations controlling even inadvertent RF/MW emissions, such as those arising from unsuppressed motors and switches, since these can interfere with licensed communications. For the public, then, the higher levels of exposure usually arise from licensed transmitters associated with broadcasting and telecommunications. Of course, this includes transmitters operated by the public, such as radio-telephones, amateur radio transmitters, and, of course, cellular telephones. Because most of these are low-power transmitters (amateur radio apart) they are not covered by Western standards, because these exclude devices having basepower less than 7 Watts. Nevertheless, these devices generate significant fields within a few inches of the antenna, and if the antenna is attached to the handpiece the user's head may be exposed to power flux densities above 1000 microwatts/square centimetre when the device is transmitting[8]. Such exposures are likely to be large relative to those in areas accessible to the public near cell sites (a few microwatts/square centimetre) or even high-power FM radio and TV transmitters (up to 20 microwatts/square centimetre). But these exposures are under the user's control, and there are strategies available to the user who wishes to practise prudent avoidance. These include holding the antenna away from the head when transmitting, or using alternative means of communication. The choices made by users will reflect their knowledge about the possible effects of exposure, their consequent perception of personal risk, and the value they place on the convenience of using the transmitting device.

In contrast, persons exposed to significant fields near cell sites or other transmission facilities may be totally unaware of their exposure or of its possible effects, and they have no practical means of directly reducing their exposure other than moving further from the source. In practical terms, it must be the operator's responsibility to ensure that exposure does not exceed an acceptable level. Here the costs, both in dollars and inconvenience, must be borne by the operator, while the public reaps the benefit of reduced exposure.

In such circumstances, how can an "acceptable level of exposure" best be determined? Public participation in the standard-setting process has been held to be an ideal solution, but in many Western countries, including New Zealand, this has been pre-empted by the existence of a standard in which there was no public participation. Reasonable alternatives would presumably all involve critical discussion of the existing standard, including analysis of the data and reasoning behind the standard and consideration of the philosophical basis of standard setting. It would be hoped that this process could lead to an informed decision by the public, regarding what was acceptable. The principle of prudent avoidance would also require that the costs (to industry and the community) of lower exposure levels would be taken account of.

In New Zealand, several decisions about acceptable levels of exposure near transmitter sites have been made in local body planning hearings, resource consent hearings and Planning Tribunal hearings, but this type of forum has proven to be less than ideal for reasons outlined in the next section.

PART 4

PLANNING IMPLICATIONS OF EXPOSURE STANDARDS

4.1 Town Planning and Resource Management Acts.

Prior to the adoption of the Resource Management Act 1991, applications for consent to erect transmitters were dealt with under the Town and Country Planning Act 1977. The Planning Act was concerned with uses but did not directly address the effects of these uses on the environment. In contrast to this, the Resource Management Act deals directly with the effects of the proposed activity on the environment. In Waitakere City, RF/MW transmitters are also subject to Bylaw #25, which specifies that exposure levels shall comply with NZS 6609. However, this bylaw applies only to transmitters having basepower exceeding l kilowatt; since most commercial and amateur transmitters have basepowers well below this value, they do not have to comply with the bylaw. This seems inconsistent with the intent of the bylaw, since it is certainly possible for directional antennae to be used in such a way that exposures near them could easily exceed maximum levels permitted under NZS 6609, even with basepower well below 1 kilowatt.

Under the Resource Management Act, an application to erect a transmitter must show, amongst other things, that relevant health and safety standards are met. In applications to date, the typical approach has been to provide evidence that radiation levels associated with operation of the transmitter would comply with the NZ Standard 6609. It is common for such evidence to be buttressed by statements about the "safeness" of NZS 6609 relative to some other Western standards, often accompanied by references to expert testimony on this theme given at previous planning hearings. Sometimes, there is also an attempt to discredit Eastern European standards, presumably in anticipation of references that might be made to these stricter standards by objectors to the application.

Evidence that the application complies with NZS 6609 is usually in the form of engineering calculations showing that under worst-case conditions (maximum possible transmission power being broadcast continuously) the maximum exposure level at any point accessible to the general public falls below the maximum exposure level specified in NZS 6609. In some applications it has also been possible to provide measured (as opposed to calculated) levels from similar sites already in operation.

Those objections to the application that cite radiation concerns generally take three lines of attack. Firstly, they question the adequacy of NZS 6609 to provide protection against athermal effects, often with reference to Eastern European standards. Secondly, they question the assumption underlying the use of calculations rather than actual measurements. Thirdly, they point out that the application fails to take account of radiation from sources other than the proposed installation (this is frequently the case). In addition, in recent cases, there is evidence of a growing public awareness of some of the technical problems with NZS 6609, particularly in the procedures laid down for monitoring compliance.

Resource consent hearings proceed by hearing first the application and supporting evidence, then the objections, and finally a reply by the applicant. The committee may question the applicant, objectors and witnesses before moving to reach a decision. The technical nature of the radiation issue is ill-suited to the hearing process. The complex technical arguments about the basis of standards, the nature of biological effects of radiation, and the practicalities of compliance testing, are all difficult to comprehend under even ideal circumstances, such as a well-planned and delivered lecture. Committee members are unlikely to be familiar with electromagnetic theory, phenomena and units of measurement. They are even less likely to be enlightened by the unbalanced arguments put forward by applicant and objectors. The procedure is frustrating for all parties because of the constraints on free discussion and debate. In particular, the objectors are likely to feel disadvantaged By not having the last say. Public participation, in the form of objectors and their witnesses, may be seen as having a different status, less credibility perhaps, relative to the applicant's team of expert witnesses. To a large extent, this derives from the fact that the witnesses for the applicant profess independent status, whereas the objectors, whatever their expertise, usually have a personal interest at stake.

Objectors are inclined to view expert witnesses employed by the applicant with suspicion, presuming that these witnesses are paid to present opinions that will support the applicant's case. Rightly or wrongly, they are unlikely to accept such expert testimony as being impartial.

Despite these impediments to fairness and truth, however, planning committees generally have managed to identify three of the critical questions as the following:

1. Is there a substantial safety margin between the NZS 6609 maximum permitted levels and the probable maximum levels near the transmitting antenna? If so, and especially if the predicted levels would comply even with Eastern European standards, then a reasonable degree of protection would be obtained.

2. Is the additive effect of radiation from other sources likely to have a significant effect on exposure levels near the antenna? If not, the calculated levels are probably reasonably predictive of actual measured levels.

3. Will the applicant take responsibility for monitoring compliance with the standard once the transmitter is operational? Properly handled, this would provide a means of detecting any significant changes in exposure levels near the transmitter.

The process by which these questions are identified and answered at local authority hearings is not only wasteful of time and resources; by its adversarial nature and power imbalance between applicant and objector, it generates frustration, anger, helplessness and other negative feelings. Objectors often feel that the scales are tipped against them not only because of their limited resources, but also because Councils will be reluctant to make decisions they cannot afford to defend in the Planning Tribunal against more-resourceful applicants.

A fourth critical question for the planning committee is this: After hearing the evidence and discussion, do the public accept that a reasonable degree of protection is provided? If the public still believes that there is a health risk, and the application is nevertheless approved, then the public may subsequently experience valid health effects as a consequence of their beliefs. This is a consequence of exposure to an unacceptable risk. To say that this would be a psychosomatic effect is not to invalidate it, but rather to characterize its nature. It is as much a health effect as the direct heating effect of relatively high levels of radiation exposure. It is well established by stress research that electromagnetic radiation scores high as an "uncertain risk" leading to biological stress. Legitimate public concerns must be sympathetically addressed if this source of stress is to be eliminated.

4.2 Demonstrating compliance with the standard.

4.2.1 Introduction.

As noted above, the public has expressed concern about the ability of local authorities to monitor compliance with the standard. Council committees are usually unaware of the technical problems inherent in the measurement and interpretation of RF/MW radiation fields, not to speak of the expense involved in instrumentation and expertise. Usually, the applicant is asked to arrange for measurements to be made and interpreted, and the result sent to Council as evidence of compliance. But objectors are unlikely to accept that such an arrangement is adequate unless it is subject to external audit by objectors or their representative. Unfortunately, there are too many ambiguities in the standard to expect the public to accept, without consultation, any particular interpretation of how compliance should be assessed.

4.2.2 Instrumentation and measurement procedures.

NZS 6609 gives detailed procedures only for occupational exposure. It is unclear whether these are also to be used for public exposure. The instrumentation required (broadband probes and meters) is expensive to buy (about NZ$ 20,000), and periodic calibration is difficult to arrange. The procedures laid down for occupational exposure require both electric and magnetic fields to be measured within the near field of the transmitting antenna *(for typical cellphone cell-site BTS antennae, the near field extends about 5 metres from the antenna. For TV antennae, the near field may extend 100 metres or more).* Yet magnetic field probes are not available for frequencies above 300 MHz.

4.2.3 Interpretation of responsibility.

Since the standard specifies maximum exposure levels in areas accessible to the general public, it seems that measurements should be taken in those areas where antenna radiation patterns indicate that exposures are likely to be highest. This will be in areas in line with the side-lobes in the vertical radiation pattern. Within those areas the highest levels will be found at points near reflecting surfaces where corresponding phases of incident and reflected electromagnetic waves can add together. This means that the highest exposures are really a product of the incident radiation and the features of the area being radiated.
Alterations to the radiated properties or structures can markedly increase or decrease the measured exposure levels in adjacent areas. Is the operator still responsible for an increase in measured exposure if it is caused by some factor outside the operator's control? This issue is not covered by the standard.

4.2.4 Calculated exposure levels.

Because calculated levels cannot take into account the effects of reflection from objects in the radiation field, they may therefore overestimate or underestimate point measurements by as much as four times. The standard does restrict how close to a reflecting surface measurements can be taken, but this is to control for the possibility of spurious measurements due to direct induction of current in the measuring instrument, rather than to prevent the measurement of reflection effects. Another source of inaccuracy in calculations of exposure levels is introduced by the practice of using "smoothed" radiation patterns as a basis for the calculations. Such "smoothing" spuriously reduces the increases in radiation level over small areas due to side-lobes in the vertical radiation pattern. It is clear that calculated levels, while they give a fair indication of overall exposure levels, cannot be used as a basis for determining compliance.

4.2.5 Multiple radiation sources and cumulative effects.

The standard does not specify how to determine responsibility in cases where exposures exceed permitted values because of cumulative effects of radiation from different sources belonging to different operators. For example, exposure levels in one area may result from contributions from two cell sites belonging to different operators plus a local FM radio transmitter. Each installation might well comply if the others were not there, but together they might exceed the permissible exposure levels.

In reality, the likelihood of significant cumulative effects is small unless the transmitters are all located within a small area of the order of perhaps 100 metres in radius. The strength of radiated fields falls off as the square of the distance from the antenna, so doubling the distance from the antenna, in any particular direction, results in the field strength being divided by four.
Multiplying the distance by ten corresponds to dividing the field strength by one hundred, and so on. However, because radiation cannot be seen, and because the location of all transmitters in any locality may not be known, there is only one way to be sure of the exposure levels, and that is to measure them with a broadband probe and meter.

4.2.6 Summary.

It will be seen that there are many potential problems in arriving at a procedure for monitoring of compliance that is acceptable to the public. All parties need to be aware of these problems and willing to reach agreement about what is required at any particular site. It is not enough for the applicant to agree to comply with the standard or any revisions of the standard. Ambiguities and technical deficiencies in the standard result in the compliance procedure being too open to interpretation. If the process is to be fair, the public, and not just the operator and the Council, must participate in this interpretation.

PART 5

ALTERNATIVE APPROACHES FOR SEEKING RESOURCE CONSENT FOR TRANSMITTERS.

5.1 Goals to be considered when making applications for resource consent.

There are four relevant goals that could be considered by operators when deciding how to get consent for new transmission facilities.

1) Minimal inconvenience and cost to applicant and public should be incurred in the resource consent process.

2) Engineering and siting should minimize radiation exposure in areas accessible to the public, while achieving adequate engineering goals.

3) Public acceptance of safety of the proposal should be maximized.

4) Likely revisions of radiation safety standards should be anticipated, so that the viability of the site is not affected in the future by downward revisions of maximum exposure levels.

The exclusion of any of these goals, or excessive weighting of some relative to others, could result in unnecessary difficulties.

In the past, a typical approach has been to use legal and technical expert evidence to attempt to intimidate objectors and Council committees by sheer weight of resources brought to bear. Here the sole goal (not listed above) is to win at whatever cost. This approach is probably best suited to applications where none of the four goals above is achievable because the proposal is outside the bounds of what is acceptable to the public. Eventually it may well be successful, so long as some authority can be persuaded that the proposal conforms to current safety standards. However, resources must then be put into defending a poor public image, preserving current safety standards, and security against possible sabotage.

5.2 The preferred alternative.

If projected radiation levels are sufficiently low, it should be possible to achieve all four of the above goals during the resource consent process. The key concept is public information and frank discussion. This consists of sharing with the interested public all the relevant information and helping them to reach a level of understanding sufficient for them to decide whether the proposal is acceptable. This does not mean giving the public only information that is consistent with the managerial aims of the applicant and exposing them to sympathetic (to the applicant) expert opinion. If this is necessary, the applicant may do well to consider alternative engineering possibilities. What is indicated is a full disclosure of relevant facts about radiation and a range of opinions about their interpretation. Given the complex and technical nature of what has to be considered, understanding may have to be facilitated by some disinterested person or persons who both the applicant and the public can trust to be fair.

5.3 Public expectations.

It is likely that the public would expect to have calculated levels confirmed by actual measurements taken as soon as transmitters are commissioned. Probably, the public would expect the measurements to be done by a suitably experienced, independent person and the results of the survey then communicated to the public. An Australian review panel recently recommended that the concerned public have an opportunity for the airing of all fears, apprehensions and misapprehensions about possible adverse effects. They recommended that this airing should take place in the light of full information and rational discussion in a sympathetic atmosphere, and that the process allow genuine participatory involvement of the public in the community health decision, consistent with the principle of informed consent.[27]

This procedure may avoid the expense and inconvenience, to all parties, of one or more lengthy hearings of a formal and adversarial type, and the inevitable alienation of public objectors to the proposal. It should promote the public knowledge of the nature of the radiation risk and of the nature of the effects from which they might seek protection. Finally, it provides a framework for the exchange of points of view, between the applicant, the public and the local authority, that permits all the relevant issues to be identified and dealt with before the question of acceptability is settled.

12 March, 1993

ADDENDUM

Radiation levels at cell sites.

The engineering characteristics of typical cell sites permit resource consent applications that are probably within the bounds of what is publicly acceptable, at least in regard to health concerns. The technical data on the transmitters and antennae, provided recently by applicants for cell sites, show that calculated worst-case maximum exposure near ground level, from an antenna placed 20 meters above ground level, is about 4 microwatts/square centimetre. As is shown in Figure SAR.2a, this level is well below that at which athermal biological effects of continuous fields have been demonstrated, and it is below all but the most stringent of the Eastern European exposure limits (Czechoslovakia, 1984; see also Figure STAN.l). Even if allowance is made for amplification of fields near reflective surfaces, the levels are likely to be acceptable by all but the Czech standard. There is a sizeable safety margin below maximum levels permitted by both NZS 6609 (200 microwatts) and the lowest level considered likely following revision of this standard (50 microwatts).

In addition, it must be remembered that the worst-case calculation assumes that all transmitters are operating at maximum strength all the time, whereas the reality is that the typical level would be only a small percentage of this. Even when allowances are made for uncertainties about how measurements should be taken and interpreted, it seems that a good margin of safety would be preserved. Assuming that the transmitter pole was surrounded by flat terrain, the maximum radiation level would be about 30 metres out from the base of the pole and would be less at smaller or larger distances.

The value of 4 microwatts/square centimetre should also be assessed in relation to public exposure levels that are typical in other places. Surveys in major cities in the U.S. have shown that the median RF/MW exposure level (50% of the population exposed above or below this level) is about five-thousandths of a microwatt/square centimetre. About one person in 200 is exposed to one microwatt/square centimetre or more. The higher exposure levels were found near transmission masts for local FM radio and television stations[37]. No metropolitan surveys have been reported in New Zealand cities. However, in Waitakere City, levels in a residential area near a TV and FM radio transmitter were found in 1990 to be higher than 200 microwatts/square centimetres, but now have been reduced to a maximum of 20 microwatts/square centimetres.

There is some natural background RF/MW radiation from the earth, the sun, and beyond the solar system, but this usually would not exceed a millionth of a microwatt/square centimetre.

In summary, the likely maximum exposure level near a typical cell site, around 4 *microwatts/square centimetre, affords a reasonable margin of safety relative to known biological effects of continuous RF/MW fields) including athermal effects of uncertain biological significance. It conforms with adopted standards in all Western and most Eastern European countries. It is considerably lower than existing exposure levels in some residential areas in New Zealand. The 4 microwatt/square centimetre exposure level is nevertheless high relative to average exposure levels found in surveys of large U.S. cities.*

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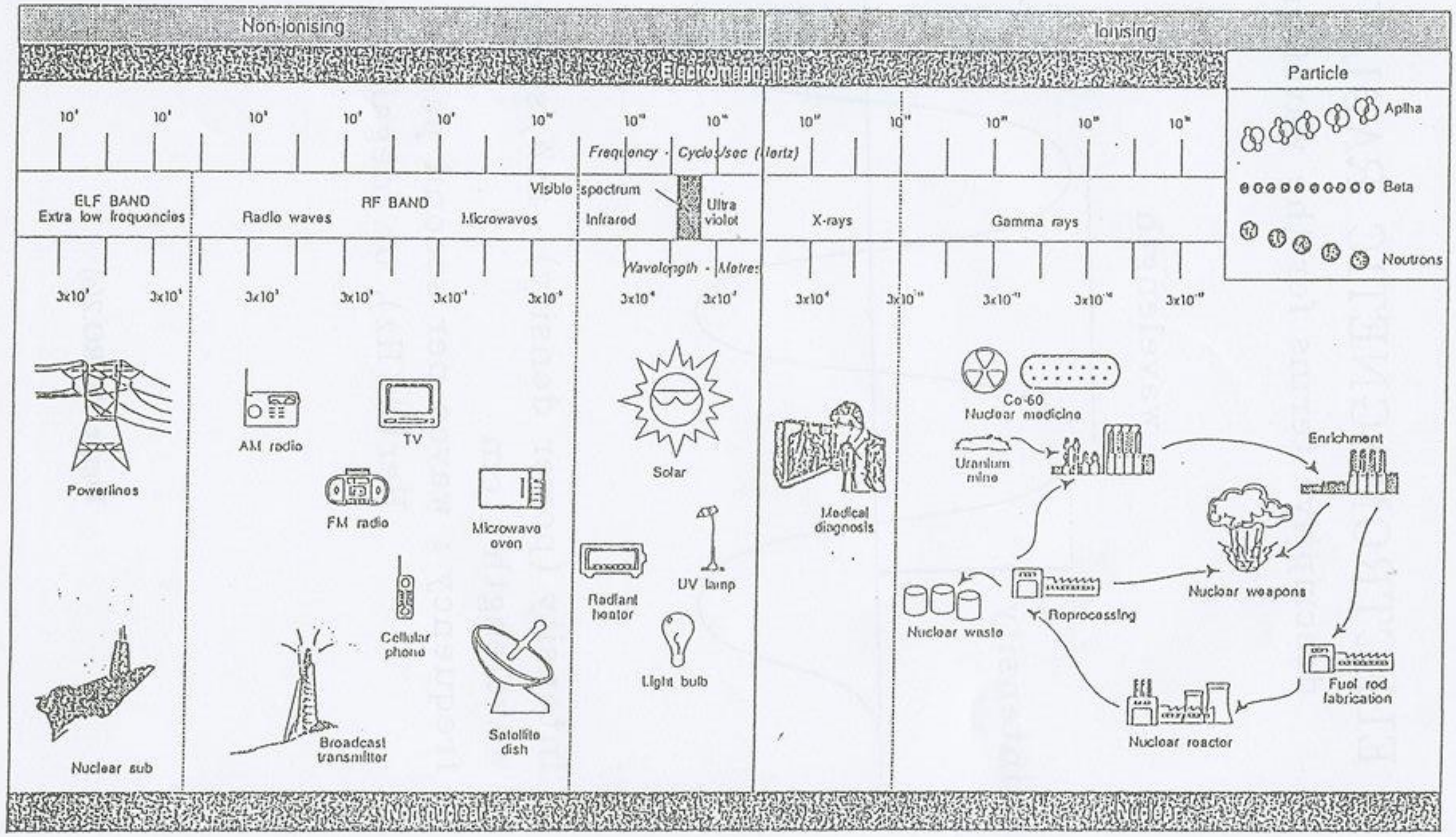
FIGURES

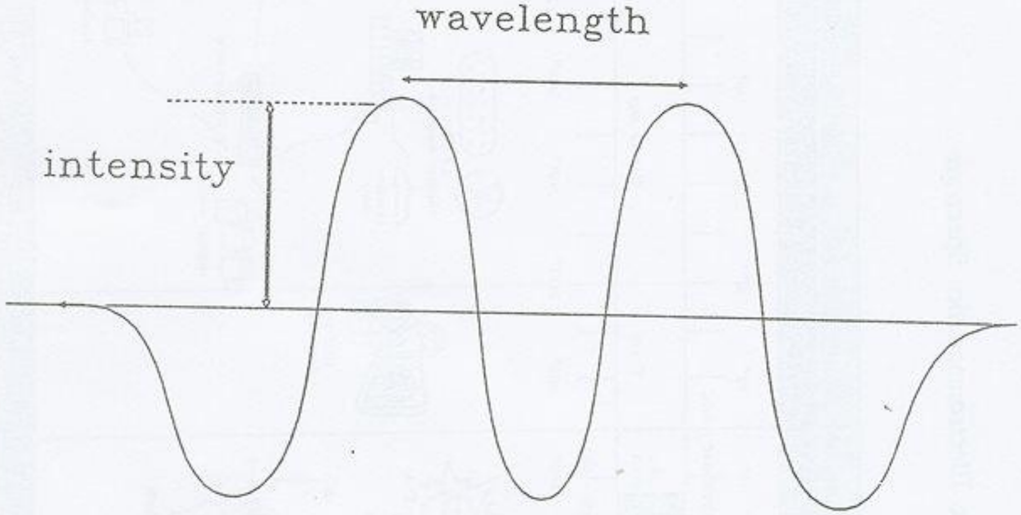
Figure INTRO.1 The Electromagnetic Spectrum

Speed of EMR: 3×10^8 metres/sec
Wavelength: 3×10^8 /frequency



ELECTROMAGNETIC RADIATION

descriptive terms for the waveform

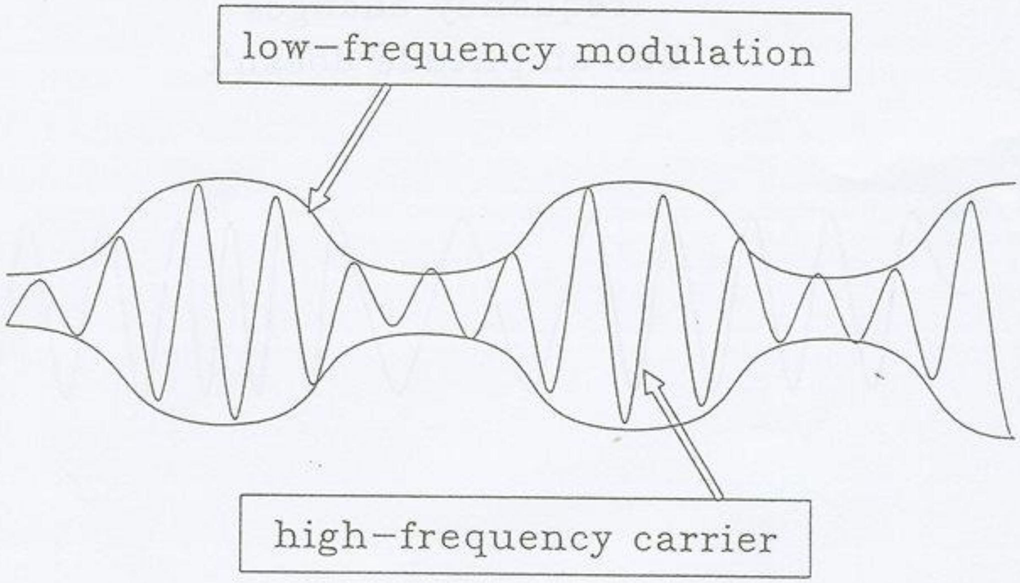


Intensity (power density): mW/sq cm
wavelength : cm
frequency : waves per second past a point
Hertz (Hz), or megaHertz (MHz)

Figure INTRO.2(a)

modulation

amplitude modulation



TV video signal is amplitude modulated at 50 Hz (extra low frequency)

Figure INTRO.2(b)

modulation

frequency modulation

frequency changes
but amplitude doesn't

cellphone transmissions are
frequency modulated

Figure INTRO.2(c)

Figure SAR.1

Dose corresponding to demonstrated biological threshold effects, and recommended maximum dose for RF/MW exposure

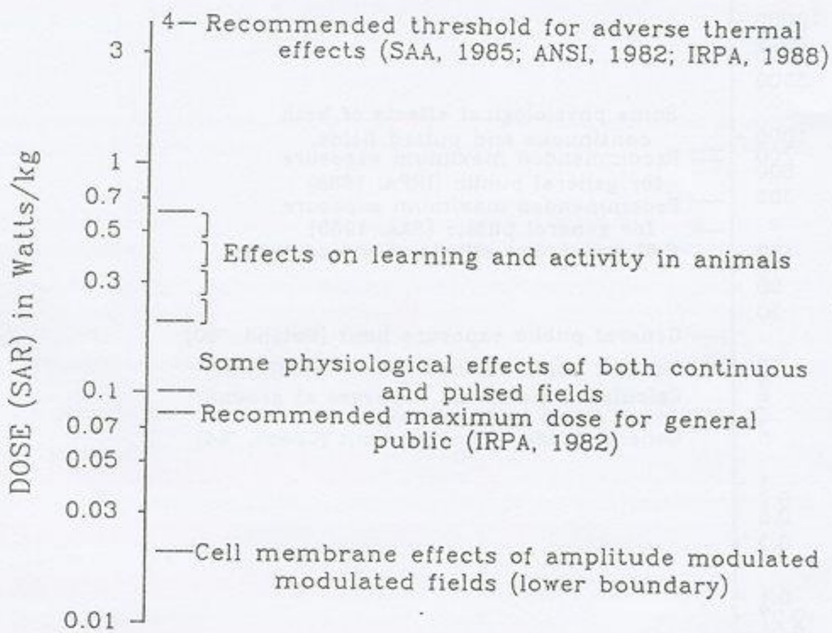


Figure SAR.2a

Power Flux Densities at 900MHz corresponding to doses in Figure SAR.1

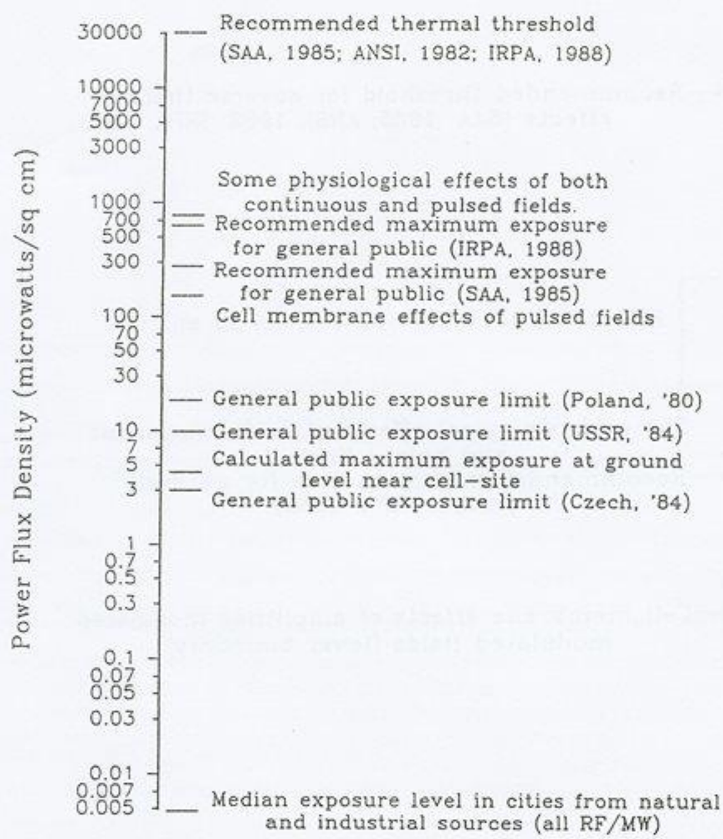


Figure SAR.2b

Power Flux Densities at 30–300MHz corresponding to doses in Figure SAR.1

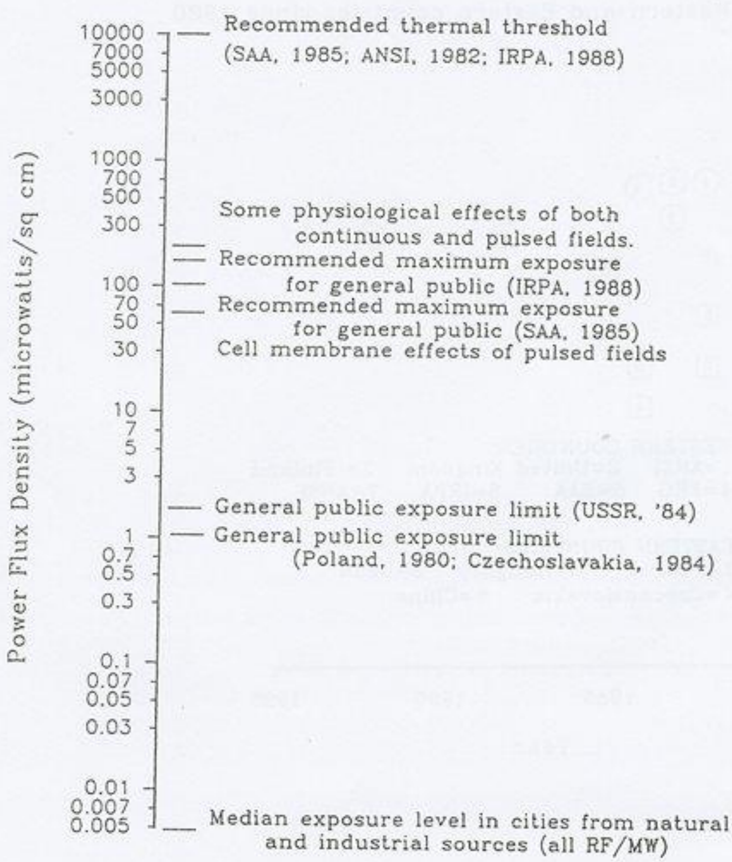


FIGURE STAN.1

Continuous exposure limits and dates of introduction, for 900 MHz in Western and Eastern countries since 1980

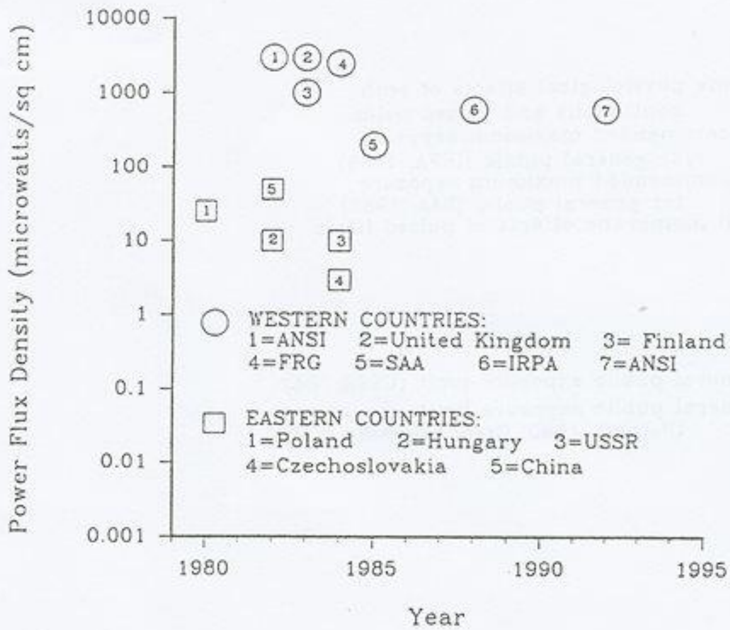


FIGURE STAN.2

Continuous exposure limits and dates of introduction, for 30–300 MHz in Western and Eastern countries since 1980

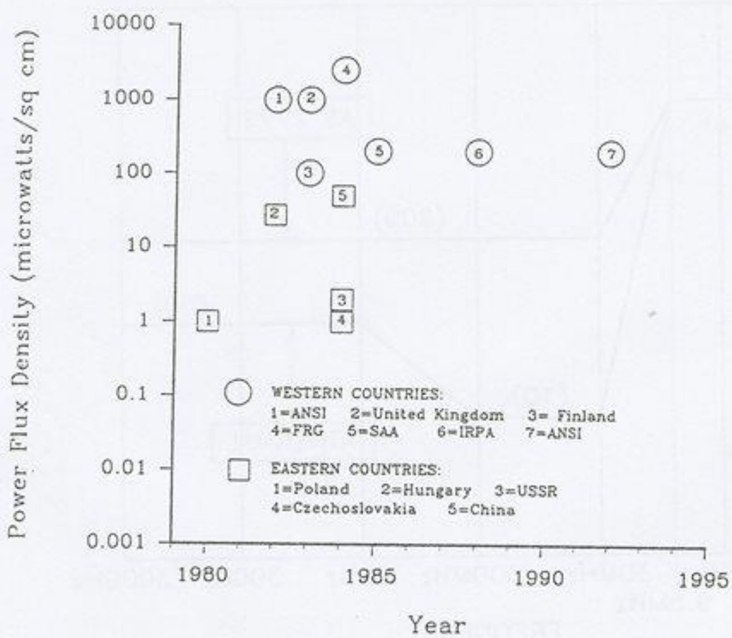


FIGURE STAN.3: Maximum permitted exposure levels (general public) derived from known athermal effects. [AS 2772 also shown for comparison].