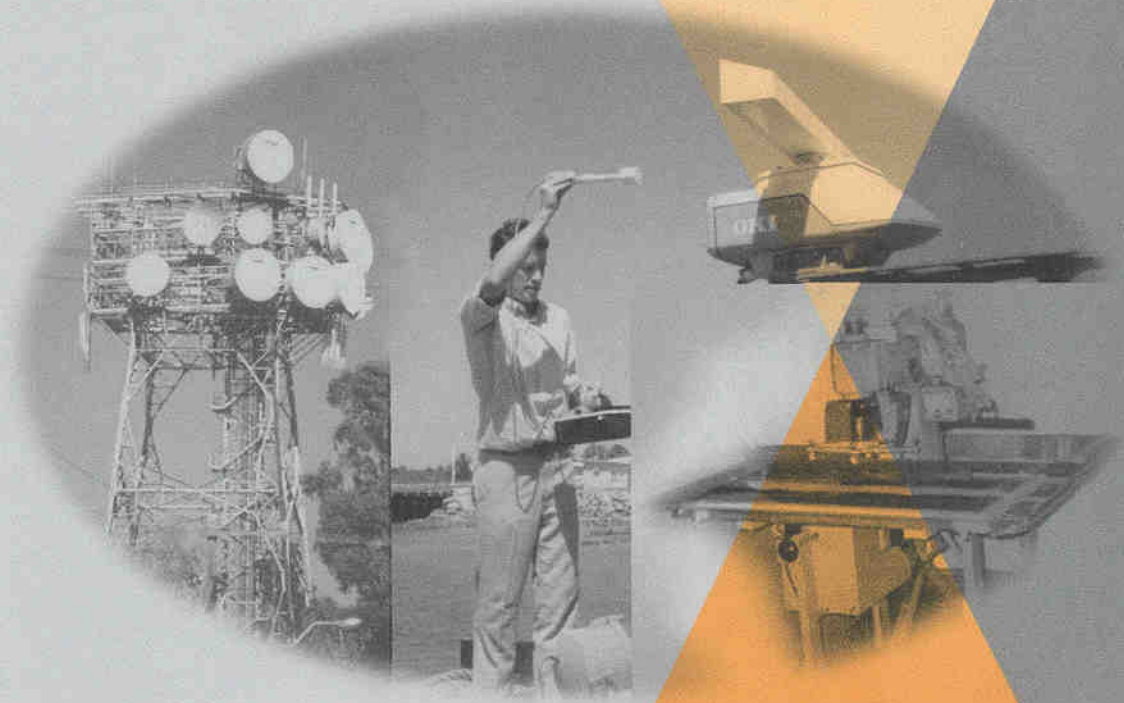
RADIATION PROTECTION STANDARD

Maximum Exposure Levels to Radiofrequency Fields - 3 kHz to 300 GHz



RADIATION PROTECTION SERIES No. 3

AUSTRALIAN RADIATION PROTECTION AND NUCLEAR SAFETY AGENCY

ARPANSA

Radiation Protection Series

The ***Radiation Protection Series*** is published by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) to promote practices which protect human health and the environment from the possible harmful effects of radiation. ARPANSA is assisted in this task by its Radiation Health and Safety Advisory Council, which reviews the publication program for the ***Series*** and endorses documents for publication, and by its Radiation Health Committee, which oversees the preparation of draft documents and recommends publication. There are four categories of publication in the ***Series***:

Radiation Protection Standards set fundamental requirements for safety. They are prescriptive in style and may be referenced by regulatory instruments in State, Territory or Commonwealth jurisdictions. They may contain key procedural requirements regarded as essential for best international practice in radiation protection, and fundamental quantitative requirements, such as exposure limits.

Codes of Practice are also prescriptive in style and may be referenced by regulations or conditions of licence. They contain practice-specific requirements that must be satisfied to ensure an acceptable level of safety in dealings involving exposure to radiation. Requirements are expressed in 'must' statements.

Recommendations provide guidance on fundamental principles for radiation protection. They are written in an explanatory and non-regulatory style and describe the basic concepts and objectives of best international practice. Where there are related **Radiation Protection Standards** and **Codes of Practice,** they are based on the fundamental principles in the **Recommendations**.

Safety Guides provide practice-specific guidance on achieving the requirements set out in **Radiation Protection Standards** and **Codes of Practice**. They are non-prescriptive in style, but may recommend good practices. Guidance is expressed in 'should' statements, indicating that the measures recommended, or equivalent alternatives, are normally necessary in order to comply with the requirements of the **Radiation Protection Standards** and **Codes of Practice**.

In many cases, for practical convenience, prescriptive and guidance documents which are related to each other may be published together. A **Code of Practice** and a corresponding **Safety Guide** may be published within a single set of covers.

All publications in the ***Radiation Protection Series*** are informed by public comment during drafting, and **Radiation Protection Standards** and **Codes of Practice**, which may serve a regulatory function, are subject to a process of regulatory review. Further information on these consultation processes may be obtained by contacting ARPANSA.

RADIATION PROTECTION STANDARD

Maximum Exposure Levels to Radiofrequency Fields — 3 kHz to 300 GHz

Radiation Protection Series Publication No. 3

This Standard was approved by the Radiation Health Committee on 20 March 2002. On 12 April 2002 the Radiation Health & Safety Advisory Council advised the CEO that the Standard might be considered for adoption.

AUSTRALIAN RADIATION PROTECTION AND NUCLEAR SAFETY AGENCY

ARPANSA

ISBN 0-642-79405-7
ISSN 1445-9760

The mission of ARPANSA is to provide the scientific expertise and infrastructure necessary to support the objective of the ARPANS Act -- to protect the health and safety of people, and to protect the environment, from the harmful effects of radiation.

This publication incorporates corrections listed in the Errata issued 8 May 2003.

Published by the Chief Executive Officer of ARPANSA, May 2002.

Foreword

This Radiation Protection Standard (hereafter referred to as 'the Standard') sets limits for human exposure to radiofrequency (RF) fields in the frequency range 3 kHz to 300 GHz. The Standard includes:

- mandatory basic restrictions for both occupational and general public exposure involving all or part of the human body;
- indicative reference levels for measurable quantities derived from the basic restrictions;
- approaches for verification of compliance with the Standard;
- requirements for management of risk in occupational exposure and measures for protection of the general public.

The rationale for the derivation of the basic restrictions and the associated reference levels is provided in Schedule 1.

The document goes well beyond simply being a technical Standard. The working group of the Radiation Health Committee that drafted the document put an immense amount of work into reviewing the scientific literature. Annexes to the Standard include a summary of the review of epidemiological studies of exposure to RF and human health and research into bio-effects at lower levels of exposure.

As described in the rationale, the basic restrictions have been derived by examining the RF exposures that cause established health effects. There is currently a level of concern about RF exposure, which is not fully alleviated by existing scientific data. It is true that data regarding biological effects, at levels below the limits specified in the Standard, are incomplete and inconsistent. The health implications for these data are not known and such data could not be used for setting the levels of the basic restrictions in the Standard.

Research is continuing in many countries into possible effects on health arising from RF exposure. In recognition of this, the Radiation Health Committee will continue to monitor the results of this research and, where necessary, issue amendments to this document.

An annex of the Standard discusses a public health precautionary approach to RF fields. This is not a simple matter – there are costs involved in adopting precautions and the science does not at all establish even indicative parameters on which a precautionary approach might be based. In relation to the general public, the Standard, nevertheless, states the principle of minimising, as appropriate, radiofrequency exposure which is unnecessary or incidental to achievement of service objectives or process requirements, provided this can be readily achieved at reasonable expense. Any such precautionary measures should follow good engineering practice and relevant codes of practice. The incorporation of arbitrary additional safety factors beyond the exposure limits of the Standard is not supported.

Whilst public concern about human exposure to RF fields has focussed on mobile phones and their base stations, it is important to stress that the Standard applies across the RF spectrum and to the full range of activities that use RF fields. The

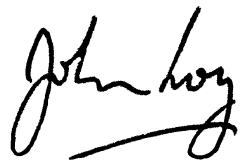
drafting of the Standard needed to bear in mind the sophisticated and complex applications of RF in telecommunications and broadcasting through to small businesses using RF welders that may in fact be much less amenable to proper control.

The Standard has been specifically devised to protect everybody, including children.

The Standard was developed by a working group of the Radiation Health Committee. The starting point for their deliberations was a draft document initially prepared by the TE/7 committee of Standards Australia. As with the TE/7 draft, the limits specified in the Standard are based on the published 1998 Guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

It is recognised that the Standard does not operate in isolation from the legal framework within Australia. Relevant Australian occupational, health, safety, and environment laws provide obligation on employers, and the designers, manufacturers and suppliers of plant or equipment, to ensure that their activities, or their plant and equipment, do not represent a risk to the health and safety of their employees or third parties who maybe affected by them. In effect, such laws require relevant parties to continually assess and improve the safety and health impact of their activities.

On 12 April 2002 the Radiation Health and Safety Advisory Council advised me that I might consider adopting the Standard, following approval of draft Standard by the Radiation Health Committee on 20 March 2002. Accordingly, I adopt this Standard and commend the Standard to relevant Australian authorities and regulatory bodies for adoption through their legal processes.



John Loy
CEO of ARPANSA

7 May 2002

Contents

1. Introduction

1.1 CITATION

This Standard may be cited as the *Radiation Protection Standard for Maximum Exposure Levels to Radiofrequency Fields — 3 kHz to 300 GHz (2002).*

1.2 BACKGROUND

Prior to the release of this Standard, Australian Standard AS 2772 '*Maximum exposure levels – Radiofrequency Radiation – 300 kHz to 300 GHz*' and its successors (Standards Australia 1985, 1990; Standards Australia/Standards New Zealand 1998) has provided the basis for standards and practices to limit general public and occupational exposure to radiofrequency (RF) radiation hazards. Over this time the Standards Australia committee responsible for the maintenance of AS 2772 (TE/7) made several attempts to update the standard to take account of current scientific findings and compliance verification techniques. In early 1998 Standards Australia and Standards New Zealand published an interim Standard, AS/NZS 2772.1(Int): 1998 (Standards Australia/Standards New Zealand 1998). The interim Standard had an expiry date set for March 1999. By April 1999 the Australian members of the committee had failed to achieve agreement on a new Australian Standard and the interim standard lapsed. Standards Australia subsequently abandoned the project to develop a new Standard.

New Zealand members of TE/7 achieved consensus on the final TE/7 draft and Standards New Zealand subsequently published a Standard (Standards New Zealand 1999) which is based on the ICNIRP Guidelines (ICNIRP 1998).

In order to safeguard community health, both ARPANSA and the Australian Communications Authority (ACA) have regulations to limit human exposure to radiofrequency fields (these were based on the expired Interim Standard). In order to maintain a robust regulatory framework within Australia, ARPANSA and ACA jointly concluded that a new Standard to limit human exposure to radiofrequency radiation was required; that the new Standard would be based upon health criteria; and that ARPANSA should develop the Standard.

A working group was established under the auspices of ARPANSA's Radiation Health Committee (RHC) to draft a set of maximum exposure levels for radiofrequency fields in the frequency range 3 kHz to 300 GHz. In choosing the members of the working group, ARPANSA consulted widely with a range of relevant groups to achieve a spread of relevant interests and expertise. The working group included expertise on electromagnetic radiation bio-effects, dosimetry and measurement techniques, medical expertise on epidemiology and occupational health and safety aspects, and knowledge of technical standards. Community and union representation was also included.

Further it was recognised that a complementary code of practice would be needed for the telecommunications industry and that this is to be developed by the Australian Communications Industry Forum (ACIF). Additional codes of practice will be developed as required for relevant areas.

The final draft of TE/7 was used as a starting point in the development of this Standard. ARPANSA wishes to acknowledge the significant work of TE/7 committee and the assistance of Standards Australia for making the final draft of the TE/7 committee available to the working group.

1.3 PURPOSE

This Standard specifies limits of human exposure to radiofrequency (RF) fields in the frequency range 3 kHz to 300 GHz, to prevent adverse health effects. These limits are defined in terms of basic restrictions for exposure of all or a part of the human body. Relevant derived reference levels are also provided as a practical means of showing compliance with the basic restrictions. In particular, this Standard specifies the following:

(a) Basic restrictions for occupational exposure with corresponding derived reference levels as a function of frequency.

(b) Basic restrictions for general public exposure, with corresponding derived reference levels as a function of frequency.

(c) Equipment and usage parameters in order to assist in the determination of compliance with this Standard.

The limits specified in this Standard are intended to be used as a basis for planning work procedures, designing protective facilities, the assessment of the efficacy of protective measures and practices, and guidance on health surveillance.

1.4 SCOPE

This Standard is applicable wherever the general public (including persons of any age or health status) may be exposed to RF fields and whenever employees may be exposed in the course of their work.

This Standard is applicable to continuous wave (CW), pulsed and modulated electromagnetic fields at single or multiple frequencies within the range 3 kHz to 300 GHz.

This Standard applies where RF fields are produced or radiated, either deliberately or incidentally, by the operation of equipment or devices. It is the responsibility of the manufacturer/supplier, installer, employer/service provider and user to ensure that all devices and installations are operated in such a way as to achieve compliance with the requirements of this Standard.

This Standard does not apply where patients are exposed to RF fields during medical exposure (see Glossary), but does apply to persons operating the radiating equipment and others who are in the vicinity during the procedure.

This Standard does not apply to other potential hazards of RF fields such as the ignition of explosives or flammable gases, or to interference to electronic equipment which are the province of other Standards.

The limits specified in this Standard represent acceptable levels of RF absorption in the body. Under routine occupational tasks, compliance with the limits will eliminate the possibility of RF burns or shock. However, for certain occupational tasks, that may involve a possibility of accidental exposure to higher levels, specific additional precautions against RF burns or shock may be required (see Section 5).

1.5 STRUCTURE

This Standard is structured as follows:

Section 1 provides introductory and background material for the Standard.

Section 2 specifies the basic restrictions and reference levels for different parts of the radiofrequency spectrum.

Section 3 describes how to handle simultaneous exposure to multiple frequency fields.

Section 4 also sets out the procedures to be followed for verification of compliance with the basic restrictions and reference levels. Clause 4.4 permits 'type-testing of RF sources or RF site evaluation' for RF installations in order to demonstrate compliance without actual measurement of each source or site. In recognition that certain classes of low-powered devices are incapable of producing exposures in excess of the basic restrictions, Schedule 5 specifies particular parameters for specific mobile or portable transmitting equipment, that will ensure compliance with the basic restrictions of this Standard without the need for further measurements.

Section 5 specifies appropriate risk management practice in relation to both occupational and general public exposure. Section 5 provides some basic considerations for occupational selection and use of personal protective equipment.

Schedules to the Standard form an integral part of the Standard. Schedule 1 provides the rationale for the basic restrictions and reference levels adopted in the Standard. It covers in detail the consideration given to different aspects of the scientific literature by the working group in the drafting process, and provides an update in a number of areas on information included in previous Standards and Guidelines. Schedules 2 and 3 provide look-up tables of reference levels.

Annexes 1, 2 and 5 provide information on technical matters relating to quantities and units, coupling mechanisms and field measurement of radiofrequency exposure levels. Annexes 3 and 4 provide updated reviews of research on epidemiological studies and bio-effects at low levels of exposure. Annex 6 provides information on public health cautionary approaches. Annex 7 provides information on medical placement assessment of persons occupationally exposed to RF fields. Annex 8 provides contact information for relevant radiation protection and regulatory authorities. Annex 9 provides a list of radiation protection series publications.

Terms used in the Standard are defined in the Glossary.

1.6 INTERPRETATION

In interpreting the provisions of the Standard, the words 'must' and 'should' have particular meanings. The presence of the word 'must' indicates that the requirement to which it refers is mandatory. The presence of the word 'should' indicates a recommendation - that is, a requirement that is to be applied as far as is practicable in the interests of reducing risk.

Schedules to the Standard form an integral part of the Standard.

Annexes to the Standard provide information supplementary to the requirements embodied in the Standard. Annexes provide material that will help in interpretation of the Standard, and background information relevant to the development of the Standard.

2. Basic restrictions and reference levels for exposure to RF fields between 3 kHz and 300 GHz

2.1 APPLICATION

This Section specifies limits of exposure for both 'occupational' and 'general public' groups. These groups are distinguished by their potential level of exposure and are defined by the degree of control and the level of training they have, as distinct from whether or not an exposure is likely to occur in the workplace (see Section 5).

Occupational exposure (see Glossary) is permitted only after thorough risk analysis has been performed and the appropriate risk management and control regimes are in force (see Section 5). General public exposure is less controlled and in many cases members of the general public are unaware of their exposure to RF fields. Moreover, individual members of the general public may be continually exposed and cannot reasonably be expected to take precautions to minimise or avoid exposure. These considerations underlie the application of more stringent exposure restrictions for the general public than for the occupationally exposed population.

2.2 BASIC RESTRICTIONS AND REFERENCE LEVELS

Mandatory limits on exposure to RF fields are based on established health effects and are termed 'basic restrictions'. Protection against established adverse health effects requires that these basic restrictions are not exceeded. Depending on frequency, the physical quantities used to specify the basic restrictions are current density (J), specific absorption rate (SAR), specific absorption (SA) and power flux density (S).

However, these mandatory basic restrictions are specified as quantities that are often impractical to measure. Therefore, reference levels (unperturbed ambient electric and magnetic fields, induced limb currents and contact currents), utilising quantities that are more practical to measure, are provided as an alternative means of showing compliance with the mandatory basic restrictions. Provided that all basic restrictions are met and adverse effects can be excluded, the reference levels may be exceeded. The reference levels have been conservatively formulated such that compliance with the reference levels given in these guidelines will ensure compliance with the basic restrictions. The relationship between basic restrictions and corresponding reference levels is shown in Table 1.

TABLE 1

RELATIONSHIP BETWEEN BASIC RESTRICTIONS AND REFERENCE LEVELS

Basic restriction	Corresponding reference levels
Instantaneous spatial peak rms current density (3 kHz-10 MHz)	Instantaneous rms E and/or H (3 kHz - 10 MHz) and instantaneous contact currents (3 kHz - 10 MHz)
Whole body average SAR (100 kHz - 6 GHz)	Time averaged rms E and/or H (100 kHz – 6 GHz)
Spatial peak SAR in limbs (100 kHz – 6 GHz)	Time averaged rms E and/or H (100 kHz– 6 GHz) and/or induced limb currents for the legs and arms (10 MHz-110 MHz) and contact point currents (100 kHz - 110 MHz)
Spatial peak SAR in head & torso (100 kHz - 6 GHz)	Time averaged rms E and/or H (100 kHz - 6 GHz)
Spatial peak SA in the head (300 MHz - 6 GHz)	Instantaneous rms E and/or H or equivalent power flux density (300 MHz - 6 GHz)
Instantaneous spatial peak SAR in head & torso (10 MHz - 6 GHz)	Instantaneous rms E and/or H or equivalent power flux density (10 MHz - 6 GHz)
Time averaged and instantaneous power flux density (6 GHz–300 GHz)	Time averaged and instantaneous rms E and/or H (6 GHz - 300 GHz)

NOTE: The 'and/or' implies that the either both quantities or individual quantities can be measured to show compliance with the basic restrictions, depending on the circumstances of exposure.

2.3 BASIC RESTRICTIONS

The basic restrictions for whole-body average SAR, spatial peak SAR, spatial peak SA, instantaneous spatial peak SAR, instantaneous spatial peak rms current density, time averaged power flux density and instantaneous power flux density are specified in Tables 2, 3, 4, 5 and 6.

Different criteria were used in the development of basic restrictions for various frequency ranges, i.e.

(a) In the frequency range between 3 kHz and 10 MHz, basic restrictions are provided on instantaneous spatial peak rms current density to prevent electrostimulation of excitable tissue. Electrostimulatory effects can be induced over short time periods and consequently instantaneous rms limits are applied (see Table 5).

(b) In the frequency range between 100 kHz and 6 GHz, basic restrictions on whole body average SAR are provided to prevent whole-body heat stress. Basic restrictions on spatial peak SAR, in the head and torso and in the limbs, are intended to prevent excessive localised temperature rise in tissue. Due to thermal inertia of tissue, a six minute averaging time is appropriate for time averaged SAR measurements (see Table 2).

(c) In the frequency range between 100 kHz and 6 GHz range, restrictions are provided on both current density and SAR where both quantities are relevant to this frequency range (see Tables 5 and Table 2).

(d) For pulse modulated exposures in the frequency range between 300 MHz and 6 GHz, basic restrictions are provided on specific absorption (SA) per pulse for localised exposures to the head. This restriction is applied in order to limit or avoid annoying or startling auditory effects (i.e. microwave hearing effect) caused by a thermoelastic mechanism associated with rapid heating in the head (see Table 3).

(e) In the frequency range between 10 MHz and 6 GHz, basic restrictions are provided on instantaneous spatial peak SAR to protect against effects associated with extremely high level pulsed fields (see Table 4).

(f) In the frequency range above 6 GHz and up to 300 GHz, basic restrictions are provided on both instantaneous and time averaged incident power flux density to prevent excessive heating in tissue at or near the body surface and to protect against effects associated with extremely high level pulsed fields (see Table 6).

TABLE 2

BASIC RESTRICTIONS FOR WHOLE BODY AVERAGE SAR AND SPATIAL PEAK SAR

Exposure category	Frequency range	Whole-body average SAR (W/kg)	Spatial peak SAR in the head & torso (W/kg)	Spatial peak SAR in limbs (W/kg)
Occupational	100 kHz–6 GHz	0.4	10	20
General public	100 kHz–6 GHz	0.08	2	4

NOTES:

1 For comparison with the limits in Table 2, the measured or calculated SAR exposure level should be averaged over any six minute period.

2 Whole body average SAR is determined by dividing the total power absorbed in the body by the total mass of the body.

3 Spatial peak SAR averaging mass is any 10 g of contiguous tissue in the shape of a cube.

TABLE 3

BASIC RESTRICTION FOR SPATIAL PEAK SA APPLICABLE TO PULSED OR AMPLITUDE MODULATED EXPOSURE

Exposure category	Frequency range	Spatial peak SA in the head within any 50 μs interval (mJ/kg)
Occupational	300 MHz–6 GHz	10
General public	300 MHz–6 GHz	2

NOTE: Spatial peak specific absorption (SA) is determined by evaluating the total energy delivered to any 10 g of contiguous tissue in the shape of a cube tissue within any 50 μs period.

TABLE 4

BASIC RESTRICTION FOR INSTANTANEOUS SPATIAL PEAK SAR APPLICABLE TO PULSED OR AMPLITUDE MODULATED EXPOSURE

Exposure category	Frequency range	Instantaneous spatial peak SAR in the head and torso (W/kg)
Occupational	10 MHz–6 GHz	10 000
General public	10 MHz–6 GHz	2 000

NOTE: Instantaneous spatial peak SAR is determined by evaluating the total energy delivered to any 10 g of contiguous tissue in the shape of a cube tissue within any 1 μs period. It is recognised that it is generally not practical to measure RF fields over such a short averaging time and that an estimate can be obtained through knowledge of the temporal characteristics of each specific source.

TABLE 5

BASIC RESTRICTIONS FOR INSTANTANEOUS SPATIAL PEAK RMS CURRENT DENSITY IN THE HEAD AND TORSO

Exposure category	Frequency range	Current density in the head and torso (mA/m² rms)
Occupational	3 kHz –10 MHz	$10 \times f$
General public	3 kHz –10 MHz	$2 \times f$

NOTES:

1 ***f* is the frequency in kHz**.

2 Because of the electrical inhomogeneity of the body, current densities must be averaged over a circular cross-section of 1 cm² perpendicular to the current direction.

3 For pulsed magnetic field exposures spanning frequencies up to 100 kHz, the maximum current density associated with the pulses can be calculated from the maximum rate of change of magnetic flux density using Faraday's law of induction. For comparison with the limit in Table 5, the maximum current density so obtained should be divided by a factor of $\sqrt{2}$ at a frequency of $f = 1/(2000 \times t_p)$, where t_p is the duration of the pulse cycle such that $1/(2000 \times t_p)$ corresponds to the second harmonic of the pulses. Alternatively, for periodic pulses the rms spectral content (where the rms averaging time is $2/(2000 \times f)$ seconds) of the current densities induced by the magnetic pulses may be determined and aggregated according to Section 3 for comparison with the basic restrictions.

TABLE 6

BASIC RESTRICTIONS FOR TIME AVERAGED AND INSTANTANEOUS INCIDENT POWER FLUX DENSITY

Exposure category	Frequency range	Time averaged power flux density (W/m²)	Instantaneous power flux density (W/m²)
Occupational	6 GHz–300 GHz	50	50 000
General public	6 GHz–300 GHz	10	10 000

NOTES:

1 Power flux densities may be averaged over an area no larger than that described in Section 2.7 (c) and (d).

2 The maximum spatial peak time averaged power flux density, spatially averaged over 1 cm², must not exceed 20 times the time averaged values indicated above.

3 For determination of time averaged values at frequencies below 10 GHz, an averaging time of six minutes applies and for frequencies above 10 GHz an averaging time of $68/f^{1.05}$ minutes **(where *f* is the frequency in GHz)** must be used. This approach compensates for progressively shorter penetration depth as the frequency increases.

4 Instantaneous power flux density is calculated over any 1 μs period. It is recognised that it is generally not practical to measure RF fields over such a short averaging time and that an estimate can be obtained through knowledge of the temporal characteristics of each specific source.

2.4 REFERENCE LEVELS

Table 7 specifies the reference levels for time averaged exposure to ambient electric (E) and magnetic (H) fields. Table 8 specifies the corresponding reference levels for instantaneous field exposure. These reference levels are illustrated in Figures 1 and 2 and look-up tables are provided in Schedules 2 and 3. Schedule 4 provides further information on equivalent power flux density.

The E and H reference levels have been derived from the basic restrictions by mathematical modelling and laboratory investigations. They are given for the condition of maximum coupling of the field to the exposed individual for all circumstances, and therefore are generally more conservative than the corresponding basic restrictions. An excellent public information resource for RF dosimetry is available from the following US Air Force web site: www.brooks.af.mil/AFRL/HED/hedr/dosimetry.html

For the purposes of demonstrating compliance with the basic restrictions, the reference levels for the electric and magnetic fields should be considered separately and not additively. This is because, for protection purposes, the currents induced by electric and magnetic fields are not additive.

At frequencies below 10 MHz the derived magnetic field strength instantaneous reference levels are designed to satisfy the basic restrictions on instantaneous spatial peak rms current density (J). H is not a good surrogate for J and as a result the corresponding reference levels have been very conservatively formulated to ensure compliance with the basic restrictions on instantaneous spatial peak rms current density. A more appropriate reference level for J is dB/dt, the rate of change of magnetic flux density, though there is presently a paucity of hazard field meters to read this metric. However if dB/dt can be obtained then it is possible to calculate a good estimate of the instantaneous spatial peak current density in the body by Faraday's law of induction (Bleaney & Bleaney 1991):

$$\oint_L \mathbf{E} \cdot d\mathbf{l} = -\int_S \frac{\partial \mathbf{B}}{\partial t} \cdot d\mathbf{S} \qquad (1)$$

For exposure of a homogeneous tissue sample to a uniform magnetic flux density (B), the maximum current will flow in a circular path at the outer radius R of a tissue plane normal to the applied magnetic flux. In such circumstances, the current density is given by:

$$J = \tfrac{1}{2}\sigma R \frac{dB}{dt} \qquad (2)$$

where σ is the conductivity of the tissue medium and J is the instantaneous (not rms) current density.

The instantaneous electric field strength reference levels below 10 MHz, are formulated to protect against receiving a contact shock from a large ungrounded conductive object that has been passively charged by the exposure field. At frequencies below 100 kHz, the possibility of this hazard is substantially mitigated if there are no conductive charged objects in the exposure area, in which case the instantaneous **occupational** E field reference level may by increased by a factor of 2.

At frequencies above 10 MHz, the derived electric and magnetic field reference levels were obtained from the whole-body SAR basic restriction using computational and experimental data. The energy coupling between a human body and an incident field reaches a maximum between 20 MHz and several hundred MHz. In this frequency range, the derived reference levels have minimum values. The derived magnetic field strengths were calculated from the electric field strengths by using the far-field relationship between E and H (E/H = 376.7 ohms ≈ 377 ohms). In the near-field, the SAR frequency dependence curves are no longer valid; moreover, the contributions of the electric and magnetic field components have to be considered separately. For a conservative estimate, field exposure levels can be used for near-field assessment since the coupling of energy from the electric or magnetic field contribution cannot exceed the SAR restrictions. For a more accurate assessment, basic restrictions on the whole-body average and local SAR should be used.

TABLE 7

REFERENCE LEVELS FOR TIME AVERAGED EXPOSURE TO RMS ELECTRIC AND MAGNETIC FIELDS (UNPERTURBED FIELDS)

Exposure category	Frequency range	E-field strength (V/m rms)	H-field strength (A/m rms)	Equivalent plane wave power flux density S_{eq} (W/m^2)
Occupational	100 kHz – 1 MHz	614	$1.63/f$	—
	1 MHz – 10 MHz	$614/f$	$1.63/f$	$1000/f^2$ (see note 5)
	10 MHz – 400 MHz	61.4	0.163	10 (see note 5)
	400 MHz – 2 GHz	$3.07 \times f^{0.5}$	$0.00814 \times f^{0.5}$	$f/40$
	2 GHz – 300 GHz	137	0.364	50
General public	100 kHz – 150 kHz	86.8	4.86	—
	150 kHz – 1 MHz	86.8	$0.729/f$	—
	1 MHz – 10 MHz	$86.8/f^{0.5}$	$0.729/f$	—
	10 MHz – 400 MHz	27.4	0.0729	2 (see note 6)
	400 MHz – 2 GHz	$1.37 \times f^{0.5}$	$0.00364 \times f^{0.5}$	$f/200$
	2 GHz – 300 GHz	61.4	0.163	10

NOTES:

1 ***f* is the frequency in MHz**.

2 For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2 and H^2 must be averaged over any 6 minute period.

3 For frequencies exceeding 10 GHz, S_{eq}, E^2 and H^2 must be averaged over any $9.6 \times 10^4 / f^{1.05}$ minute period (see note 1).

4 Spatial averaging of the time averaged reference levels of Table 7 should be performed according to the requirements of clause 2.7.

5 For occupational exposure, E and H reference levels of Table 7 are given in plane wave ratio at frequencies greater than or equal to 1 MHz. However, for many occupational exposure situations, equivalent plane wave power flux density is not an appropriate metric if 'far-field' exposure conditions do not apply. Survey meters may be calibrated in terms of W/m^2, but both E and H will generally require independent measurement and evaluation if measured in the near-field.

6 For general public exposure E and H reference levels of Table 7 are given in plane wave ratio at frequencies greater than or equal to 10 MHz. However, equivalent plane wave power flux density is not an appropriate metric if 'far-field' exposure conditions do not apply. Survey meters may be calibrated in terms of W/m^2, but both E and H will generally require independent measurement and evaluation if measured in the near-field.

TABLE 8

REFERENCE LEVELS FOR EXPOSURE TO INSTANTANEOUS RMS ELECTRIC AND MAGNETIC FIELDS (UNPERTURBED FIELDS)

Exposure category	Frequency range	E-field strength (V/m rms)	H-field strength (A/m rms)	Equivalent plane wave power flux density S_{eq} (W/m^2)
Occupational	3 Khz – 65 kHz	614	25.0	—
	65 kHz – 100 kHz	614	$1.63 / f$	—
	100 kHz – 1 MHz	$3452 \times f^{0.75}$	$9.16 / f^{0.25}$	—
	1MHz – 10 MHz	$3452 / f^{0.25}$	$9.16 / f^{0.25}$	$(10^9/f)^{0.5}$ (see note 4)
	10 MHz – 400 MHz	1941	5.15	10 000 (see note 4)
	400 MHz – 2 GHz	$97 \times f^{0.5}$	$0.258 \times f^{0.5}$	$25 \times f$
	2 GHz – 300 GHz	4340	11.5	50 000
General public	3 kHz – 100 kHz	86.8	4.86	—
	100 kHz – 150 kHz	$488 \times f^{0.75}$	4.86	—
	150 kHz – 1 MHz	$488 \times f^{0.75}$	$3.47 / f^{0.178}$	—
	1 MHz – 10 MHz	$488 \times f^{0.25}$	$3.47 / f^{0.178}$	—
	10 MHz – 400 MHz	868	2.30	2 000 (see note 5)
	400 MHz – 2 GHz	$43.4 \times f^{0.5}$	$0.115 \times f^{0.5}$	$5 \times f$
	2 GHz – 300 GHz	1941	5.15	10 000

NOTES:

1 ***f* is the frequency in MHz**.

2 For the specific case of occupational exposure to frequencies below 100 kHz, and where adverse effects from contact with passively or actively energised conductive objects can be excluded such that Table 9 would not apply (refer Note 3 Table 9), the derived electric field strength can be increased by a factor of 2.

3 The E and H reference levels in Table 8 are instantaneous rms values and for purposes of compliance determination, measurements are to be rms averaged over any 1 μs period. However, at frequencies below 100 kHz, measurements may be rms averaged over any 100 μs period or, below 10 kHz, at least one single cycle of the carrier frequency.

4 For occupational exposure, E and H reference levels of Table 8 are given in plane wave ratio at frequencies greater than or equal to 1 MHz. However, for many occupational exposure situations, equivalent plane wave power flux density is not an appropriate metric if 'far-field' exposure conditions do not apply. Survey meters may be calibrated in terms of W/m^2, but both E and H will generally require independent measurement and evaluation if measured in the near-field.

5 For general public exposure E and H reference levels of Table 8 are given in plane wave ratio at frequencies greater than or equal to 10 MHz. However, equivalent plane wave power flux density is not an appropriate metric if 'far-field' exposure conditions do not apply. Survey meters may be calibrated in terms of W/m^2, but both E and H will generally require independent measurement and evaluation if measured in the near-field.

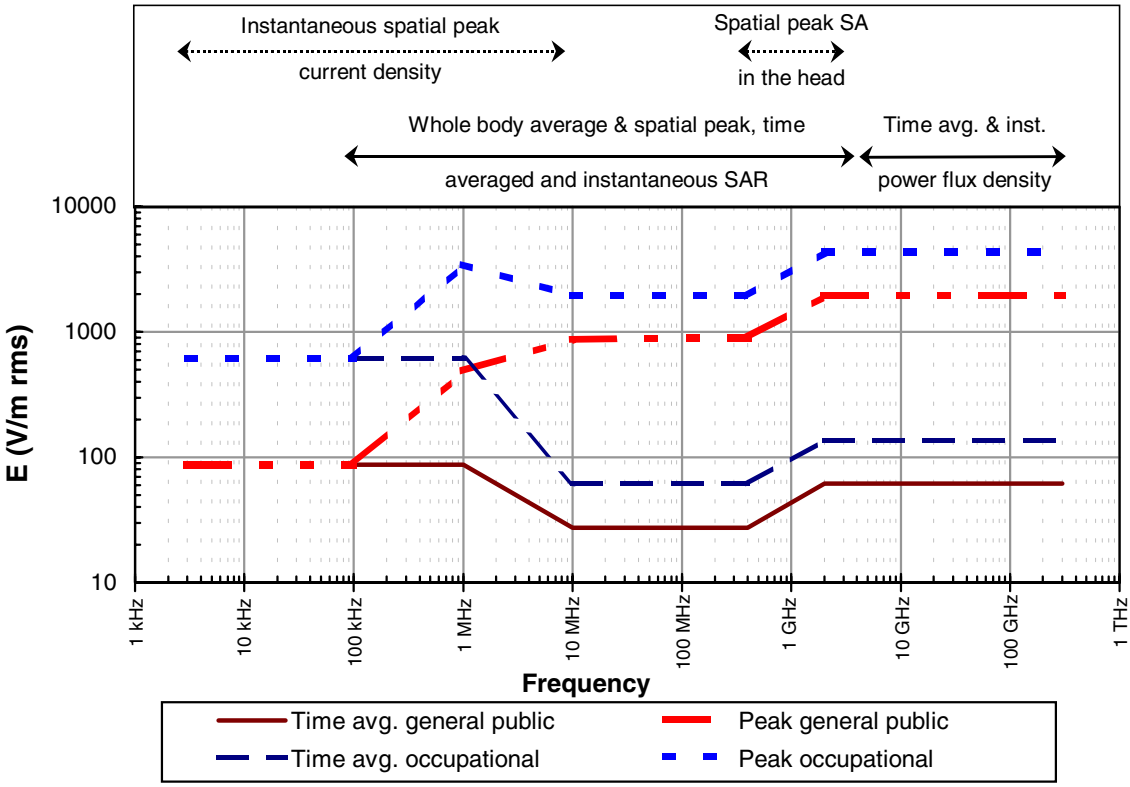


Figure 1 Reference levels for instantaneous and time averaged rms exposure to electric fields (refer Tables 7 & 8 and look-up tables in Schedules 2 and 3).

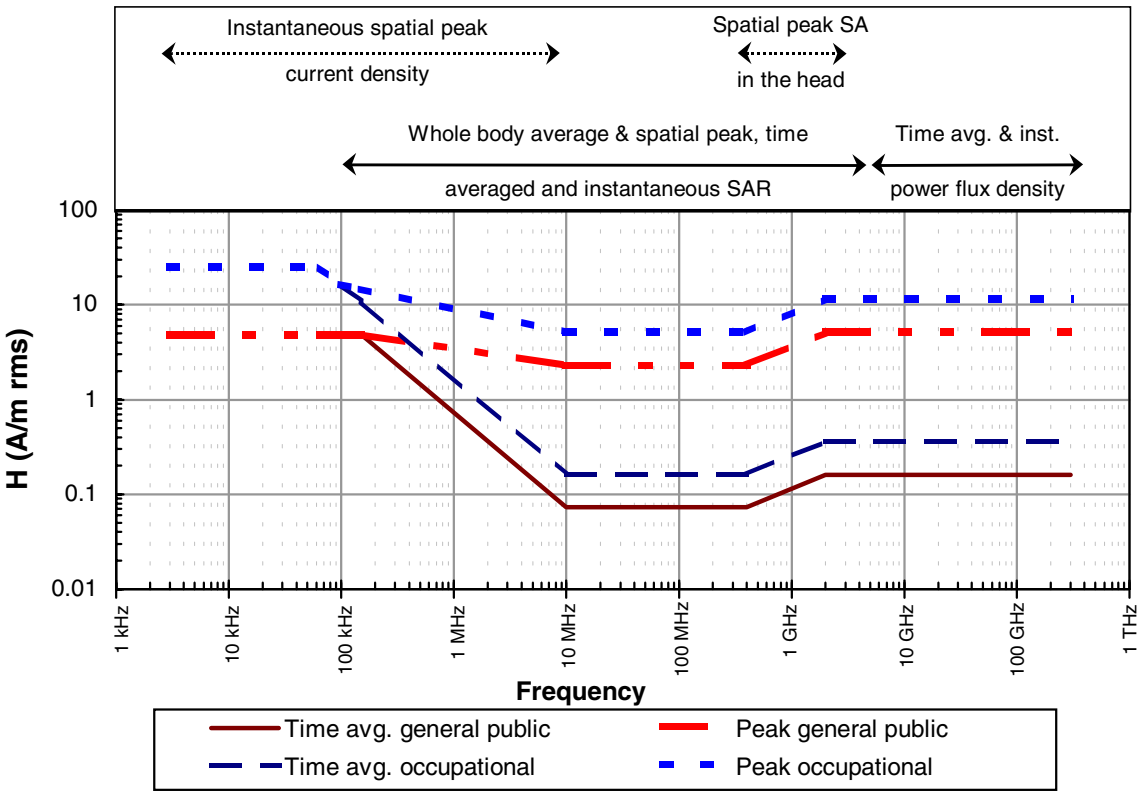


Figure 2 Reference levels for instantaneous and time averaged rms exposure to magnetic fields (refer Tables 7 & 8 and look-up tables in Schedules 2 and 3).

2.5 REFERENCE LEVELS FOR CONTACT CURRENTS

For frequencies up to 110MHz, reference levels for point contact current are given in Table 9. Above these levels caution must be exercised to avoid shock and burn hazards arising from high spatial peak current densities during point contact with energised or passively charged conductive objects. For further information, refer American National Standards Institute C 95.3 Standard (ANSI 1991).

TABLE 9

REFERENCE LEVELS FOR INSTANTANEOUS RMS CONTACT CURRENTS FROM POINT CONTACT WITH CONDUCTIVE OBJECTS

Exposure category	Frequency range	Maximum contact current (mA rms)
Occupational	3 kHz–100 kHz	$0.4 \times f$
	100 kHz –110 MHz	40
General public	3 kHz–100 kHz	$0.2 \times f$
	100 kHz –110 MHz	20

NOTES:

1 ***f* is the frequency in kHz**.

2 For frequencies greater than or equal to 100 kHz, instantaneous contact currents must be rms averaged over any 1 μs period. However, at frequencies below 100 kHz, measurements must be rms averaged over any 100 μs period or, below 10 kHz, over at least one single cycle of the carrier frequency.

3 The reference levels of Table 9 are applicable only where there is a possibility of point contact with passively or actively energised conductive objects such that significant instantaneous spatial peak current densities are likely (e.g. where current is drawn through a finger rather than induced in an arm).

2.6 REFERENCE LEVELS FOR LIMB CURRENTS

For the frequency range 10 MHz–110 MHz, reference levels for time averaged rms limb currents are provided in Table 10, to ensure compliance with the basic restrictions for spatial peak SAR in the limbs (see Table 2).

TABLE 10

REFERENCE LEVELS FOR TIME AVERAGED RMS CURRENT INDUCED IN ANY LIMB

Exposure category	Frequency range rms	Current (mA rms)
Occupational	10 MHz – 110 MHz	100
General public	10 MHz – 110 MHz	45

NOTE: For compliance with the basic restriction on spatial peak SAR in limbs, induced limb current measurements are to be rms averaged over any 6-minute period.

2.7 SPATIAL AVERAGING OF E AND H FIELDS

The E and H reference levels given in Table 7 and Table 8 are unnecessarily conservative if applied as spatial peak limits. Consequently, time averaged E^2 and H^2 measurements may be spatially averaged provided that the basic restrictions on spatial peak SAR and instantaneous spatial peak rms current density are not exceeded (see clause 2.3). The implementation of an appropriate spatial averaging scheme is not a simple matter to determine. There are many technical issues that should be considered including: nature of the source (primary or scattered fields), proximity to the sources, dimensions of exposed body parts relative to the wavelength, and the number of sampling points.

Although different methods may be employed, the following spatial averaging methods are recommended.

(a) For frequencies below 100 MHz:

Calculate the spatial average for a standing person by averaging four single measurements at the head, chest, groin and knees. For determining compliance of a seated operator of a high power RF device (e.g. a RF plastic welding machine), measurements should be averaged over the head, chest and groin only. The spatially averaged values so obtained should be compared to the field limits shown in Table 7 and Table 8. None of the individual field strength spot measurements are allowed to exceed these limits by a factor of √20 (a factor of √20 for field strength [E or H] or a factor of 20 for S, E^2 or H^2).

Where a person extends their hands or feet into a higher field area, a measurement should be taken at the hands or feet. This measured level should not exceed the reference levels shown in Table 7 and Table 8 by a factor of √20 (as above) or more. Alternatively, limb current measurements may be compared to the limits of Table 10.

(b) For frequencies in the range 100 MHz to 1 GHz

Conduct scanning measurements over the body and locate the spatial peak level. Make three measurements in a vertical line separated by the distance indicated in Table 11 and centred at the location of the spatial peak level. Average the three measurements and compare to the reference levels shown in Table 7 and Table 8.

(c) For frequencies above 1 GHz up to 10 GHz

Conduct scanning measurements over the body and locate the spatial peak level. Make four measurements at the corners of a vertical square with side lengths as indicated in Table 11 and centred at the location of the spatial peak. Average the measurements (including the value in the centre of the square) and compare to the field limits shown in Table 7 and Table 8.

(d) For frequencies above 10 GHz

Conduct scanning measurements over the body and locate the spatial peak level. Average the E or H measured levels over a square of 20 cm² centred at this location. Spatial maximum E or H averaged over 1 cm² should not exceed √20 times the reference levels in Table 7 and Table 8.

TABLE 11

SPATIAL AVERAGING DIMENSION

Frequency range	Distance d (cm)
100 MHz – 10 GHz	$30 - 2.58 \times (f - 0.1)$
10 GHz – 300 GHz	4.5

NOTE: f is the frequency in GHz.

3. Simultaneous exposure to multiple frequency fields

3.1 General principles

In situations of simultaneous exposure to fields of different frequencies and depending upon the nature of exposure and the distribution of RF absorption within the body, the combined effects of exposure to multiple frequency exposure sources may be additive. It is therefore important that such exposures are evaluated appropriately for compliance with this Standard. Appropriate consideration must be given to all relevant basic restrictions (or reference levels) for whole body heating effects and for each smaller region or part of the body that may be simultaneously affected.

In general, electrostimulatory effects that may result from exposure to frequencies below 10 MHz are not considered to be additive with heating effects produced by exposure to frequencies above 100 kHz and may be treated independently.

For evaluation of multiple frequency exposure to particular parts of the body, the averaging mass or surface area chosen for analysis must match the appropriate parameter specified for each basic restriction or reference level.

Although no specific formulation is given for the treatment of short RF pulses, these must be considered if high-energy RF pulses are likely to occur simultaneously.

A simpler but more conservative approach to the following methodology would be to divide the sum of the multiple exposure levels by the most stringent level or restriction within the relevant frequency range.

3.2 Electrostimulation

To guard against electrostimulation using current density basic restrictions, the following condition must apply at any location in the head and torso, at any instant in time:

$$\sum_{i=3\,\mathrm{kHz}}^{10\,\mathrm{MHz}} \frac{J_i}{J_{L,i}} \leq 1 \qquad (3)$$

where

J_i = the instantaneous spatial peak rms current density induced at frequency i.

J_{Li} = the instantaneous spatial peak rms current density restriction at frequency i as given in Table 5.

When applying the corresponding reference levels for peak spatial E and H, and contact currents I_c, the following conditions must be observed at the measurement location at any instant in time:

$$\sum_{i=3\,kHz}^{10\,MHz} \frac{E_i}{E_{L,\,i}} \leq 1 \qquad (4)$$

and

$$\sum_{j=3\,kHz}^{10\,MHz} \frac{H_j}{H_{L,\,j}} \leq 1 \qquad (5)$$

and

$$\sum_{n=3\,kHz}^{10\,MHz} \frac{I_n}{I_{C,\,n}} \leq 1 \qquad (6)$$

where

- E_i = the instantaneous peak rms electric field strength at frequency i
- $E_{L,I}$ = the instantaneous rms electric field reference level from Table 8
- H_j = the instantaneous peak rms magnetic field strength at frequency j
- $H_{L,j}$ = the instantaneous rms magnetic field reference level from Table 8.
- I_n = the instantaneous peak rms contact current component at frequency n
- $I_{C,n}$ = the instantaneous rms reference level of contact current at frequency n (see Table 9).

3.3 LOCALISED BODY HEATING

The sum of localised SARs induced at any point in the body from combined exposures between 100 kHz and 6 GHz must not exceed the relevant basic restriction for head and torso, or the limbs.

For reference level measurements, the time averaged currents induced in a limb, and the instantaneous touch currents at a point of contact must satisfy the following conditions:

$$\sum_{k\,=\,10\ MHz}^{110\ MHz} \left(\frac{I_k}{I_{L,\ k}} \right)^2 \leq 1 \qquad (7)$$

and

$$\sum_{n=100\,kHz}^{110\,MHz}\left(\frac{I_n}{I_{C,n}}\right)^2 \le 1 \qquad (8)$$

where

I_k = the time averaged rms limb current component at frequency k
$I_{L,k}$ = the time averaged rms reference level of limb current at frequency k (see Table 10)
I_n = the six minute time averaged rms contact current component at frequency n (see note)
$I_{C,n}$ = the instantaneous rms reference level for contact current at frequency n (see Table 9).

NOTE: Since equation 8 is used to assess the heating effect of the contact currents, a six minute averaging time applies to the measured rms levels of equation 8.

3.4 WHOLE BODY HEATING

To guard against whole body heating effects from combined frequency exposures, the summed whole body average (WBA) SAR and incident power flux density must satisfy the following condition:

$$\sum_{i=100\,kHz}^{6\,GHz}\frac{SAR_i}{SAR_L}+\sum_{i>6\,GHz}^{300\,GHz}\frac{S_i}{S_L}\le 1 \qquad (9)$$

where

SAR_i = the time averaged WBA SAR caused by exposure at frequency *i*
SAR_L = the time averaged WBA SAR limit given in Table 2
S_L = the time averaged power flux density limit given in Table 6
S_i = the time averaged power flux density at frequency *i*.

NOTE: The second term in equation (9) may be replaced by equivalent WBA SAR terms arising from power flux density exposures above 6 GHz.

If applying the corresponding E and H reference levels, then the following conditions must apply:

$$\sum_{i=100\,kHz}^{300\,GHz}\left(\frac{E_i}{E_{L,i}}\right)^2 \le 1 \qquad (10)$$

and

$$\sum_{j=100\,kHz}^{300\,GHz}\left(\frac{H_j}{H_{L,j}}\right)^2 \le 1 \qquad (11)$$

where

E_i = the time averaged rms electric field strength at frequency i
$E_{L,i}$ = the time averaged rms electric field reference level from Table 7
H_j = the time averaged rms magnetic field strength at frequency j
$H_{L,j}$ = the time averaged rms magnetic field reference level from Table 7

3.5 ADDITIONAL REMARKS

The conditional relationships 4, 5, 10 and 11 involve reference levels and they assume 'worst case' conditions among the fields from the multiple sources. As a result, typical exposure situations may, in practice, require less restrictive exposure levels than would otherwise be indicated by such relationships.

4. Verification of compliance with the basic restrictions and reference levels

4.1 GENERAL

The mandatory basic restrictions in this Standard are specified through quantities that are often difficult and, in many cases, impractical to measure. Therefore, reference levels of exposure, which are simpler to measure, are provided as an alternative means of showing compliance with the mandatory basic restrictions. The reference levels have been conservatively formulated such that compliance with the reference levels given in this Standard will ensure compliance with the basic restrictions. If measured exposures are higher than reference levels, it does not necessarily follow that the basic restrictions have been exceeded, but a more detailed analysis is necessary to show compliance with the basic restrictions.

Unless indicated otherwise in Schedule 5, compliance with the requirements in Sections 2 and 3 must be verified by direct measurements or by evaluation.

Measurements or evaluations to prove compliance with this Standard must be made by an appropriately qualified and experienced person or authority. Following such measurements or evaluations, and where exposure levels are not increased, the results will remain valid for a period set by the testing authority.

Verification of compliance must be based on conditions leading to the highest RF field levels emitted under normal operating conditions and maximum expected duty factor. Further assessment must be made after any modification that may increase the level of human exposure.

Measurements or evaluations of occupational exposure must be made in areas reasonably accessible to workers to ensure that the relevant basic restrictions of Section 2 are not exceeded. Where the field level is variable from day to day and may exceed the occupational basic restrictions, a measurement or evaluation must be performed under those conditions which are expected to represent the most probable maximum exposures. As necessary, additional protective measures described in Section 5 must be implemented.

In areas that are reasonably accessible to the general public, measurements or evaluations of exposure must be undertaken to ensure compliance with the general public basic restrictions of Section 2.

4.2 TYPE TESTING/RF SITE EVALUATION

Type testing of RF sources or RF site evaluation may be used to demonstrate compliance with Sections 2 and 3, provided that a minimum of two similar sources or sites have been measured and the relevant levels shown to be comparable within 3 dB of equivalent power flux density.

Type testing or RF site evaluation must not be used where the RF levels are unpredictable e.g.

(a) Industrial RF heaters and plastic welders where the RF levels vary depending on the weld die or the material to be welded.

(b) Antenna structures where the RF field pattern is likely to be significantly influenced by the local ground plane conditions.

4.3 RECORDS

An up-to-date log of measurements or evaluations for the site configuration must be kept and be available for inspection by competent authorities (see Annex 8, which provides contact information for relevant radiation protection and regulatory authorities) or representatives of employees.

4.4 COMPLIANCE OF MOBILE OR PORTABLE TRANSMITTING EQUIPMENT (100 kHz TO 2.5 GHz)

Mobile or portable transmitting equipment may be designed to be used close to the body. This can result in exposure of a small portion of the user's body and produces fields with a highly non-uniform spatial distribution. In such circumstances it is practicable to determine compliance from a consideration of equipment parameters and conditions of use. Detailed compliance provisions are given and discussed in Schedule 5. The provisions of Schedule 5 apply only to mobile or portable transmitting equipment that emits RF fields at frequencies between 100 kHz and 2500 MHz.

5. Protection—occupational and general public exposure

This section prescribes processes so as to ensure that:

(a) no occupationally exposed person, aware user or person in a controlled area, is exposed to RF fields that exceed the occupational exposure limits; and

(b) no member of the general public is exposed to RF fields in excess of the general public limits.

The occupational exposure and general public limits are specified in Section 2. Advice on assessment of RF exposure levels is given in Annex 5. Occupational exposure is only permitted under controlled conditions. In particular, a thorough risk analysis must be performed, and an appropriate risk management regimen implemented, prior to the exposure occurring.

More stringent conditions are applied to the exposure of members of the general public. Individual members of the public may be continually exposed and cannot reasonably be expected to take precautions to minimise or avoid exposure. Indeed in some circumstances members of the public may not be aware that the exposure is occurring.

5.1 Managing Risk in Occupational Exposure

The following people must ensure that the hazards associated with exposure to RF fields are managed: employers; owners and operators of RF generating equipment; people in control of workplaces; designers, manufacturers and suppliers of RF generating equipment; self-employed persons.

The persons listed above are to ensure that the hazards associated with exposure to RF fields and RF-generating plant are managed by a risk management process as listed below in 5.1.2.

5.1.1 Workplace Policy

The risk management process must be implemented and should be clearly documented in a written workplace policy that expresses the commitment of all parties. The policy should identify the risks, specify the procedures that must be implemented to control and manage them, and identify those responsible for that implementation.

5.1.2 Risk Management Process

The risk management process must include:

(a) Identification of the hazards. This step should include identification of the primary RF source/s and also sources of re-radiation, where

currents are induced on conductive objects, and are potential sources of shock and burns;

(b) Assessment of the risk. This step includes assessment of exposure levels, comparison to the relevant limits and consideration of both the likelihood and severity of the consequence(s) of the hazard;

(c) Choice of the most appropriate control measures to prevent or minimise the level of risk. The control/s chosen must not cause other hazards;

(d) Implementation of the chosen control measures. This step must include maintenance requirements to ensure the ongoing effectiveness of the control/s and training on the control measures for workers potentially exposed to RF fields;

(e) Monitoring and reviewing the effectiveness of the control measures. The monitoring and review process must assess whether the chosen controls have been implemented as planned, that the control measures are effective and that the control measures have not introduced new hazards or worsened existing hazards.

5.1.3 Control Prioritization

Where there is potential for exposure above the limits, the hazard should be managed through application of the most appropriate control priorities as indicated below. The measures higher in the control priorities are usually more effective than those lower, and should be given greater consideration accordingly. In order of priority, the Control Priorities are:

(a) **Elimination** of the hazard. If this is not practical, exposure to the risk should be prevented or minimised by one or a combination of the following control measures;

(b) **Substitution** of a less hazardous (and more manageable) process or less hazardous plant; and

(c) **Engineering controls** including redesign of equipment or work processes and/or isolation of the hazard. Examples include: building in shielding, fail-safe interlocks, earthing of large metallic objects, built-in leakage detectors and alarms or utilising waveguides below cut-off;

(d) Introduction of **administrative** controls such as signage restricting access or defining exposure limit boundaries, safe work systems or down-powering or outages. Administrative controls may be used in combination with higher level controls;

(e) Use of appropriate **personal protective equipment (PPE).** All users of PPE must be provided with the appropriate PPE and trained and supervised in its use to ensure that they have a clear understanding of its correct usage and limitations and they must use

it accordingly. In addition, the PPE must be maintained and replaced as specified by the manufacturer to ensure it is kept in good condition so that its effectiveness as a control is not compromised.

Leather work gloves generally provide good protection against contact current shocks from passively charged and re-radiating structures, but are not an adequate protective measure against contact with high-power, live RF conductors.

Personal protective suits (PPS) are available to screen the user from high ambient field exposures. These garments are constructed from conductive fabrics and can provide a substantial Faraday cage shielding effect, but only if the user is *fully* enclosed in the suit. The shielding effectiveness of such suits varies with frequency, and generally provides little protection below 10 MHz. These suits could be used to enter areas above the field reference levels, but only to the extent that the shielding effectiveness of the suit provides adequate protection against the basic restrictions. In addition there should be due consideration of any additional risks created from using the suit. For example, the enclosed nature of the suits may induce a thermal load that could well exceed allowable SAR heating. Furthermore the limited visibility afforded by the hood of the suit may also prove a significant hazard when climbing tall structures.

5.1.4 Training and Supervision

RF workers must be trained in safe work practices, and supervised when appropriate. They must also be trained about the controls in place to manage the potential RF hazard. There must be appropriate procedures in place to ensure that the safe systems of work are utilised.

5.1.5 Medical Assessment

There must be procedures in place to ensure that persons who are occupationally exposed above basic restrictions for the public who have medical devices susceptible to RF interference or metallic implants are not put at risk by their exposure. It is advisable that persons who may be occupationally exposed to RF fields are subject to a placement assessment. An example of an appropriate placement assessment is given in Annex 7.

5.1.6 Notification of Competent Authorities

The competent authority must be notified in the event of an exposure exceeding the relevant limits. Annex 8 provides contact information for relevant radiation protection and regulatory authorities.

5.1.7 Assessment of Reference Levels

Advice on measurement or calculation of exposures relevant to the reference levels is given in Annex 5.

5.2 PREGNANCY

In order to reduce the risk of accidental exposure above occupational limits a pregnant woman should not be exposed to levels of RF fields above the limits of general public exposure. Occupationally exposed women who are pregnant should advise their employers when they become aware of their pregnancy. After such notification, they must not be exposed to RF fields exceeding the general public limits. Pregnancy should lead to implementation of relevant personnel policies. These include, but are not limited to, reasonable accommodation/adjustment (see Glossary) or temporary transfer to non-RF work without loss of employment benefits. Additional guidance may be found in the Pregnancy Guidelines produced by the Human Rights & Equal Opportunity Commission (HREOC 2001) at www.hreoc.gov.au/sex_discrimination/index.html (for more details see Annex 7).

5.3 PROVISION OF INFORMATION TO EMPLOYEES

Employees must be advised about the following:

(a) The precautions and procedures to be followed if they become pregnant, or have/receive metallic implants or medical devices during the time they are engaged in RF work.

(b) The known biological effects of RF fields as summarised by the World Health Organization (WHO 1993), preferably with a written explanation see (d) below.

(c) The procedures to be followed in the event of any over-exposure, including a contact point (medical specialist knowledgeable in medical effects of RF field exposures).

(d) That if they become sick they should attend their own General Practitioner (as for any illness or medical condition) and inform their doctor that they work with RF fields and give the doctor the information about RF fields referred to above (b).

5.4 ALLOWABLE EXPOSURES IN CONTROLLED AREAS

The allowable exposure limits in controlled areas (see Glossary) are the same as for occupational exposures.

5.5 RECORDS

The personnel files of workers who are occupationally exposed to RF fields should be identified and maintained so that retrospective health enquiries can be made. Such files should be retained for the full duration of, and after termination of employment as required by law.

5.6 POST INCIDENT EXPOSURE MANAGEMENT

A plan for medical management of any case of over-exposure should be developed in advance.

The following plan of action is suggested as appropriate in the event of RF over-exposure (proven or suspected):

(a) First Aid treatment should be obtained from the nearest first aider, doctor or hospital as required for burns or other injuries.

(b) Employers should arrange for employees suspected or confirmed as over-exposed to RF fields to be medically assessed as soon as possible after the over-exposure, in conjunction with a medical specialist knowledgeable in medical effects of exposure to RF fields.

(c) In the event that medical assessment of the eye is required then referral to an ophthalmic practitioner and use of the appended examination form is recommended (see Annex 7).

(d) A record of the over-exposure, the results of medical treatment, medical examinations, or assessment and follow up as advised by professional advisers, should be made in the employee's personnel file.

(e) The employer must ensure the employee is fully advised and understands the nature of the over-exposure incident and the nature and reasons for the post incident management of it.

(f) The over-exposure or incident must be investigated to determine the level and extent of exposure, and which parts of the body were possibly in the RF field. This information should be recorded as specified in (d) above. Appropriate corrective action or changes to procedures need to be instituted as soon as is reasonably practicable, with regard to preventing future over-exposures to any employees working in similar situations.

(g) Notification and recording of the over-exposure must be done as prescribed in relevant Commonwealth or State Occupational Health and Safety legislation.

Hocking (2001) provides information on the health effects of acute over-exposure and relevant aspects of clinical diagnosis.

5.7 PROTECTION OF THE GENERAL PUBLIC

Measures for the protection of members of the general public who may be exposed to RF fields due to their proximity to antennas or other RF sources must include the following:

(a) Determination of the boundaries of areas where general public exposure limits levels may be exceeded.

(b) Restriction of public access to those areas where the general public exposure limits may be exceeded.

(c) Appropriate provision of signs or notices complying with AS 1319 (Standards Australia 1994).

(d) Notification to the competent authority, as required, in the event of the exposure exceeding the relevant limits.

(e) Minimising, as appropriate, RF exposure which is unnecessary or incidental to achievement of service objectives or process requirements, provided this can be readily achieved at reasonable expense. Any such precautionary measures should follow good engineering practice and relevant codes of practice. The incorporation of arbitrary additional safety factors beyond the exposure limits of this Standard is not supported.

References and Bibliography

American National Standards Institute (ANSI) 1991, '*Recommended practice for the measurement of potentially hazardous electromagnetic fields – RF and microwave* (ANSI C95.3 – 1991), New York Institute of Electrical and Electronics Engineers, New York USA.

Bleaney, B.I. & Bleaney, B. 1991, *Electricity and Magnetism*, 3rd edn, vol. 1, Oxford University Press, Oxford UK.

Hocking, B. & Joyner, K. 1992, 'Health risk management of radiofrequency radiation', *Journal of Occupational Health and Safety – Australia and New Zealand*, vol. 8, no. 1, pp. 21-30.

Hocking, B. 1997, 'Risk management of electromagnetic compatibility with medical devices', *Journal of Occupational Health Safety – Australia and New Zealand*, vol. 13, no. 3, pp. 239-242.

Hocking, B. & Joyner, K. 1988, 'Health Aspects of RFR Accidents II A protocol for assessment of RFR accidents', *Journal of Microwave Power and Electromagnetic Energy*, vol. 23, no. 2, pp. 75-80.

Hocking, B. 2001, 'Management of Radiofrequency Radiation Overexposure', *Australian Family Physician*, vol. 30, no. 4, pp. 339-342.
[This paper is available at www.arpansa.gov.au]

Human Rights & Equal Opportunity Commission (HREOC) 2001, *Pregnancy guidelines*, Human Rights & Equal Opportunity Commission, Sydney Australia. [ISBN 0 642 26976 9]
[Refer www.hreoc.gov.au/sex_discrimination/index.html]

ICNIRP 1996, 'Health issues related to the use of hand-held radiotelephones and base transmitters. Statement of the International Commission on Non-Ionizing Radiation Protection', *Health Physics*, vol. 70, no. 4, pp. 587-593.

ICNIRP 1998, 'Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). Guidelines of the International Commission on Non-Ionizing Radiation Protection', *Health Physics*, vol. 74, no. 4, pp. 494-522.

IEC 1987, *Safety requirements for radio transmitting equipment*, publication IEC 60215, International Electrotechnical Commission, Geneva Switzerland.

ITU 2001, *Radio Regulations*, 4 vols, International Telecommunications Union, Geneva Switzerland.

National Occupational Health & Safety Commission (NOHSC), *Overview of the risk management process*, National Occupational Health & Safety Commission, Canberra Australia.
[Refer http://www.nohsc.gov.au/ohsinformation/nohscpublications/fulltext/docs/h4/881.htm]

National Occupational Health & Safety Commission (NOHSC), *Risk management for manufacturers*, National Occupational Health & Safety Commission, Canberra Australia.
[Refer http://www.nohsc.gov.au/ohsinformation/nohscpublications/fulltext/docs/h5/1512.htm]

National Occupational Health & Safety Commission (NOHSC), *Risk management in occupational health and safety*, National Occupational Health & Safety Commission, Canberra Australia.
[Refer http://www.nohsc.gov.au/ohsinformation/databases/ohslitpgm/ohslit/r/004140.htm]

Queensland Division of Workplace Health & Safety 2000, *Advisory Standard: Risk management*, Queensland Division of Workplace Health & Safety, Brisbane Australia.
[Refer www.whs.qld.gov.au/advisory]

Queensland Division of Workplace Health & Safety 2000, *Safe use in industry of radiofrequency generating plant*, Queensland Division of Workplace Health & Safety, Brisbane Australia.
[Refer www.whs.qld.gov.au/guide]

Standards Australia 1998, *The international system of units (SI) and its application*, AS ISO 1000, Standards Australia, Sydney Australia.

Standards Australia 1994, *Safety signs for the occupational environment*, AS 1319, Standards Australia, Sydney Australia.

Standards Australia 1988, *International Electrotechnical Vocabulary (all Parts)*, AS 1852, Standards Australia, Sydney Australia.

Standards Australia 1985, *Radiofrequency radiation. Part 1: Maximum exposure levels—100 kHz to 300 GHz*, AS 2772.1, Standards Australia, Sydney Australia.

Standards Australia 1990, *Radiofrequency radiation. Part 1: Maximum exposure levels—100 kHz to 300 GHz*, AS/NZS 2772.1, Standards Australia, Sydney Australia.

Standards Australia 1988, *Radiofrequency radiation. Part 2: Principles and methods of measurement – 300 kHz to 100 GHz*, AS/NZS 2772.2, Standards Australia, Sydney Australia.

Standards Australia 1995, *Guide to the installation in vehicles of mobile communication equipment intended for connection to a cellular mobile telecommunication service (CMTS)*, AS/NZS 4346, Standards Australia, Sydney Australia.

Standards Australia 1999, *Risk Management*, AS/NZS 4360, Standards Australia, Sydney Australia.

Standards Australia/Standards New Zealand 1998, *Radiofrequency fields. Part 1: Maximum exposure levels—3kHz to 300 GHz*, AS/NZS 2772.1(Int), Standards Australia, Sydney Australia.

Standards New Zealand 1999, *Radiofrequency Fields.Part 1:Maximum exposure levels 3 kHz to 300 GHz*, NZS 2772.1, Standards New Zealand, Wellington New Zealand.

World Health Organization (WHO) 1993 *Electromagnetic fields (300 Hz to 300 GHz)*, Environmental Health Criteria No. 137, United Nations Environment Programme/International Radiation Protection Association/World Health Organization, Geneva Switzerland, pp. 155-174.

Schedule 1

Rationale

Introduction

This schedule is intended to provide an explanation of the scientific basis for the derivation of RF exposure limits in this Standard. These limits are intended to provide protection against established adverse health effects.

This Standard along with other recent exposure Standards specifies fundamental limits termed 'basic restrictions'. The basic restrictions are defined in terms of those quantities that correlate most closely with the established biological effects for which protection is required. In many cases, the direct measurement of a basic restriction is often impractical or beyond the technical capability of those determining compliance. Therefore a set of indicative levels called 'reference levels' have been provided as an alternative means for determining compliance (see Clauses 2.2, 2.3 & 2.4).

This rationale provides a broad historical overview of the significant advances in both knowledge of radiofrequency (RF) biological effects and also the development of the basis and rationale that lead to the basic restrictions and reference levels specified in this Standard. It is not intended to provide an exhaustive description of all scientific knowledge in the area. However, this rationale does provide a broad overview of the scientific and philosophical considerations that lead to the derivation of the exposure limits.

Historical Evolution of Standards

It is well known that low frequency electromagnetic fields of sufficient intensity can produce electro-stimulation of both nerve and muscle tissues (e.g. electric shock from contact with an energised conductor). Nerve cells are most sensitive to electrostimulation in the frequency range of below 1000 Hz and the hazard of electric shock falls quite rapidly as the frequency of the electric field oscillation is increased.

In 1890, the French bio-physicist D'Arsonval discovered that for frequencies above 10,000 Hz (0.01 MHz), an electric current of three ampere could be used to warm the skin without triggering the nerves that normally produce painful muscular contractions at lower power line frequencies (Kloth, Morrison & Ferguson 1984; Mumford 1961). Medical therapy developed from this effect was termed 'longwave diathermy' and was conducted within the frequency range 0.05 MHz to 10 MHz in the early decades of the 20th century but was later prohibited due to problems with radio-interference.

In the 1890s, Guglielmo Marconi (Hackmann 1994) invented and developed the first wireless communications systems. In subsequent decades both the power and frequency range of RF generating equipment has steadily increased.

In 1928 it was shown that high frequency RF radiation was capable of heating internal organs of the human body (Christie 1928). Shortwave medical diathermy equipment was developed and used extensively during the 1930s for deep heat therapy (Kloth, Morrison & Ferguson 1984). Unlike longwave diathermy, shortwave diathermy does not require direct electrical contact with the skin.

Prior to the development of radar by World War II it was unlikely for anyone to be injured by radiofrequency equipment unless they were in very close proximity to a transmitter or conductor of RF energy. Soon after the Second World War there were some early investigations into possible adverse health effects. In the early 1950s there was sufficient evidence to conclude that harmful effects were associated with exposure to levels of microwave radiation above approximately 100 mW/cm^2 and that the primary mechanism for injury was related to excess heating resulting from the absorption of the microwave energy in various tissues within the body (Schwan & Piersol 1954, 1955). In 1953 the US Navy adopted a maximum continuous exposure limit of 10 mW/cm^2 for all RF and microwave frequencies in use. In 1966, the American National Standards Institute published the first edition of the C95.1 Standard (ANSI 1966) specifying a 10 mW/cm^2 human exposure limit for the frequency range from 10 MHz to 100 GHz.

Early exposure standards were inadequate because they failed to account for important physical aspects of electromagnetic wave interaction with the body. In addition to the magnitude of the applied fields, absorption of RF energy depends on the physical geometry of the body relative to the direction of the applied fields and also upon frequency dependent electrical properties of the absorbing tissue. In particular, the body, or parts of it, can act like a tuned antenna within specific RF frequency bands. Such frequency dependent resonance effects result in higher rates of energy absorption than can otherwise be estimated from simple surface area projections of the body in relation to the applied field. Additionally, highly localised absorption of the RF energy can also occur within specific frequency bands. A further limitation of the 10 mW/cm^2 limit was the implicit assumption that 'far-field' plane wave exposure was applicable to all exposure situations. However, with many exposures near to radiating equipment, such conditions do not apply.

By the late 1960s it was clear that experimentally induced microwave and RF bio-effects could be observed in small animals exposed either to continuous wave (CW) or pulsed RF and at levels significantly below the ANSI time averaged limit of 10 mW/cm^2. Effects were also observed in small volume tissue samples. Such effects appeared to be more prominent where the experimental subject was exposed to significantly high pulsed or modulated fields, where peak intensities were moderate or high, but where the time averaged levels could be comparatively lower. In the 1970s, research focused upon dosimetry aspects and the extent to which non-uniform absorption may influence biological systems. Commencing early in the 1970s, extensive dosimetry studies were carried out by various researchers, notably in the USA by Guy et al. (1975), Johnson and Guy (1983) and Gandhi (1974).

Prior to the mid 1970s, the majority of RF bio-effects data were plagued by large uncertainties which both stemmed from, and were compounded by, a poor understanding of RF dosimetry. Previous knowledge of RF energy deposition within the body depended heavily upon limited data containing a multitude of inherent assumptions (often unrealised or ignored) which vastly over-simplified the way in which RF radiation is absorbed by a human body. It was not until the development of reasonably powerful computers and other technologies (such as high sensitivity thermal imaging cameras), that significant advances could be made in the RF dosimetry area. Even today, adequate dosimetry remains as one of the most difficult and significant problems to be addressed by researchers attempting to interpret and extrapolate RF bio-effects data to a human exposure situation. This is true regardless of whether the initial biological data is obtained either from in vitro experiments or from whole animal exposure studies.

Development of Australian Standards

There were no Australian Standards to limit occupational or public RF exposure until 1985. The 10 mW/cm^2 level from ANSI was adopted as a de-facto limit in Australia from about 1955 to 1979, through various guidelines and rules imposed by authorities (Byczynski 1960; Standards Association of Australia 1972; Telecom Australia 1975; Lange 1976). In 1978, Tell implied that the 10 mW/cm^2 ANSI limit was unsuitable at certain frequencies because it could lead to excessive temperature rise in tissue (Tell 1978). Additionally, it became evident that specific absorption rate (SAR) data could be used to establish exposure limits. Proposed limits of exposure derived from a thermal model using SAR absorption data were initially published in a 1979 report issued by the Australian Radiation Laboratory (Cornelius & Viglione 1979) and later that year Standards Australia formed a committee to develop an Australian Standard. In 1981, Telecom Australia revised their exposure guidelines in accord with the newly derived limits (Hocking 1981). In the USA, the 10 mW/cm^2 limit was in force until 1982 when (ANSI 1982) revised their approach and incorporated a modern understanding of relevant exposure parameters. This approach included the frequency dependence of energy deposition in the body as determined through SAR measurement data. The first edition of AS 2772 was subsequently issued in 1985 (Standards Association of Australia 1985).

Harmonisation with International Standards

There is no single standard adopted internationally defining limits of exposure to radiofrequency radiation. However, the European Union has a recommendation for the adoption of the 1998 ICNIRP Guidelines of the International Commision on Non-Ionizing Radiation Protection (ICNIRP 1998) and many countries, including New Zealand (Standards New Zealand 1999), have standards or recommendations conforming to the ICNIRP 1998 Guidelines. The ICNIRP Guidelines are also recommended by the World Health Organization (WHO, 2000).

ICNIRP is an international scientific body with affiliations to various international standards bodies and organisations. ICNIRP rules establish scientific integrity and require that all committee members are independent experts who may not be members of commercial or industrial organisations. All ICNIRP publications appear in the peer reviewed scientific journal 'Health Physics'. As signatory to various international agreements (e.g. the General Agreement on Tariffs and Trade [GATT], now administered by the World Trade Organization [WTO]) it is established Australian Government policy to harmonise with international Standards where they exist (World Trade Organization 1994).

The development of Australian Standards that are different from international standards is only warranted in cases where it can be shown that there will be significant benefit to the Australian community. In particular, apart from specific issues associated with improved technical specification, or where ICNIRP specifications were incomplete, reasons why this Standard should differ substantially from ICNIRP exposure guidelines (ICNIRP 1998) were not identified. In this context, the final draft document prepared by TE/7 committee of Standards Australia (see Clause 1.1) incorporated limits that were based on the 1998 ICNIRP Guidelines. The TE/7 draft was used as the basis for initial discussion in the preparation of this Standard.

This Standard is based on the guidelines developed by the ICNIRP committee (ICNIRP 1998). In establishing this Standard, ARPANSA has followed the original intent of the ICNIRP Guidelines. However, the ICNIRP Guidelines do not constitute a technical Standard and in some circumstances their application may be unclear. Further, it is necessary that various Australian regulatory bodies must be able to readily interpret and implement this Standard. Consequently, the ICNIRP specifications have been reworked in order to provide a sturdy and unambiguous technical framework. However, it was not considered appropriate to substantially modify ICNIRP specifications unless there was reasonable scientific justification for doing so.

In establishing this Standard, the origins and evolution of relevant recommendations and publications of the ICNIRP and the American National Standards Institute (ANSI) were carefully reviewed. Additionally, the rationale for further development of these documents was examined and consideration given to whether any published evidence challenges the integrity of the approaches taken by the current ICNIRP (ICNIRP 1998) (formerly IRPA/INIRC) approach and the current ANSI/IEEE (IEEE 1999) approach. In addition to reviews conducted by expert groups or panels, there is a large body of literature published in peer reviewed journals which has been relied on. Recent epidemiological studies and laboratory research reports have been carefully examined for evidence that would establish a need to modify the basic restrictions or the associated reference levels. Moreover, relevant spatial and temporal measurement averaging parameters have been reviewed and where necessary revised, so as to provide an adequate and unambiguous specification of the limits.

Comparison with 1998 ICNIRP Guidelines

Relevant technical differences between the 1998 ICNIRP Guidelines and the requirements of this Standard are summarised in Table 12.

TABLE 12

SUMMARY OF DIFFERENCES BETWEEN ICNIRP 1998 GUIDELINES AND THE REQUIREMENTS OF THIS STANDARD

Item	ICNIRP 1998 Guidelines	This Standard
Frequency range covered in scope	0 Hz to 300 GHz	3 kHz to 300 GHz
Basic restriction for instantaneous spatial peak SAR in the head and torso	Not specified	Specified in Table 4. An averaging time of 1 μs applies.
Averaging time for spatial peak SA in the head	Not specified	50 μs specified in Table 3
Frequency range of spatial peak SA in the head	300 MHz to 10 GHz	300 MHz to 6 GHz
Frequency range of SAR basic restrictions	100 kHz to 10 GHz	100 kHz to 6 GHz
Frequency range of incident power flux density basic restrictions	10 GHz to 300 GHz	6 GHz to 300 GHz
Numerical precision of both time averaged and instantaneous E & H field reference levels.	Effects of numerical rounding are apparent in presentation of reference levels. Such rounding produces discontinuity between tabular frequency ranges.	ARPANSA specification in Tables 7 & 8 is a more precise numerical formulation than that shown in the ICNIRP tables. The discontinuity between frequency ranges is markedly reduced.
Averaging time for rms current density in the head and torso	Not specified	Specified in note 3 of Table 5
Averaging time for instantaneous rms E & H reference levels	Not specified	Specified in note 3 of Table 8
Method for spatial averaging of reference levels	Not specified	Specified in Clause 2.7
Method for evaluation of multiple frequency exposures	Incomplete specification	Improved specification in Section 3

NOTE: Further information on specific measurement conditions is provided later in this Schedule under the heading 'Measurement Averaging Considerations'.

Comparison with previous Australian Standard

Relevant technical differences between the previous AS/NZS 2772.1(Int):1998 Australian Standard (Standards Australia/Standards New Zealand 1998) and the requirements of this Standard are summarised in Table 13.

TABLE 13

SUMMARY OF DIFFERENCES BETWEEN THE PREVIOUS AUSTRALIAN STANDARD AND THE REQUIREMENTS OF THIS STANDARD

Item	AS/NZS 2772.1(Int):1998	This Standard
Basic restrictions on WBA SAR	Occupational 0.4 W/kg General public 0.08 W/kg	Identical to AS/NZS 2772.1(Int):1998
Basic restriction for instantaneous spatial peak rms current density in the head and torso (3 kHz-10 MHz)	Not Specified	Specified in Table 5
Basic restriction for instantaneous spatial peak SAR in the head and torso	Not specified	Specified in Table 4
Spatial peak SAR	Excludes hands, wrists, feet & ankles Occupational 8 W/kg General public 1.6 W/kg	Head and torso - 10 W/kg occupational General public 2 W/kg Limbs - 20 W/kg occupational General public 4 W/kg
Averaging mass for spatial peak SAR measurements	1 gram, otherwise 10 grams for hands, wrists, feet & ankles	10 grams for all parts of the body (also applies to SA)
Spatial peak SA in the head	Not specified	Specified in Table 3
Spatial peak SAR in the limbs	Restricted to hands, wrists, feet and ankles	Applies to any part of a limb
Frequency range of SAR basic restrictions	3 kHz to 300 GHz (did not reflect full detail of contemporary knowledge)	100 kHz to 6 GHz (basic restrictions are defined by different quantities at other frequencies)
Reference levels for rms contact currents	For occupational exposure: $1.0 \times f$ mA (3 kHz-100 kHz) where f is in kHz. 100 mA (100 kHz-30 MHz) Public exposure levels are not defined	For occupational exposure: $0.4 \times f$ mA (3 kHz-100 kHz) where f is in kHz 40 mA (100 kHz-110 MHz) General public exposure levels are exactly ½ the occupational levels above
Reference levels for rms induced limb currents	As indicated for rms contact currents above	Occupational exposure: 100 mA (10 MHz-110 MHz) General public exposure: 45 mA (10 MHz-110 MHz)
Averaging time for rms contact currents	1 s	1 μs up to 100 μs or 1 pulse cycle (refer note 2 of Table 9)
Time averaged rms E and H & S_{eq} reference levels	Constant E and H levels above 400 MHz	Similar E and H levels between 3 kHz and 400 MHz. Levels increase above 400 MHz. At frequencies above 2 GHz the levels remain constant at 5 times above the 400 MHz level (refer Table 7 and figures 1 and 2). This is, consistent with established dosimetry models and the majority of international standards.
Instantaneous rms E & H reference levels	E field limit only. 1940 V/m for both occupational and general public exposure	Specifies both E and H levels. Lower levels for general public exposure. Conservative formulation matches known biological effects and RF field coupling with the body (refer Table 8 and figures 1 and 2).

Table 13 continued over page...

TABLE 13 (continued)

SUMMARY OF DIFFERENCES BETWEEN THE PREVIOUS AUSTRALIAN STANDARD AND THE REQUIREMENTS OF THIS STANDARD

Item	AS/NZS 2772.1(Int):1998	This Standard
Averaging time for instantaneous reference levels	Not specified	Specified in note 3 of Table 8
Method for spatial averaging of reference levels	Incomplete specification	Rigorous methodology (see Clause 2.7)
Method for evaluation of multiple frequency exposures	Outlined only for E^2, H^2 and S_{eq}	Improved specification in Section 3

NOTE: Further information relating to changes in time averaged rms reference levels is provided later in this Schedule under the heading 'Measurement Averaging Considerations'.

Scientific studies into the biological effects of radiofrequency fields

Relevant scientific literature has been especially sought and examined with a view to finding evidence that the 1998 ICNIRP1998 exposure guidelines might need revision on grounds that exposure to levels within the limits could lead to adverse health effects.

Data for effects of RF exposure on living organisms was evaluated by considering the evidence of health effects in humans, and the biological effects in humans and other organisms, as well as effects at a cellular level. In establishing the exposure limits, the need to reconcile a number of differing expert opinions was recognised. The validity of scientific reports was evaluated by considering elements such as; the strength of evidence, reproducibility of effect, existence of an established relationship between occurrence of an effect and the magnitude of exposure (i.e. dose response), whether the effect follows an understood mechanism, and the extent of peer review prior to publication. In many cases, all relevant elements could not be assessed.

In particular, relevant scientific reviews (notably those of ICNIRP 1996; Royal Society of Canada 1999; and the Independent Expert Group on Mobile Phones [IEGMP] 2000) and reports on various case studies were assessed. This assessment focused on the recent literature reports subsequent to the development of the ICNIRP Guidelines (i.e. post 1997) and included consultation with researchers who were asked specific questions within their area of expertise.

Experimental Studies

A large body of literature exists on the biological effects of radio frequency radiation. Much of this research includes experimental studies performed in vitro, in vivo and on human subjects.

Experimental studies have been extensively reviewed by the IEEE (1992) and WHO (1993) and more recently by ICNIRP (1998), the Royal Society of Canada (1999) and the IEGMP (2000). Research reports have employed a wide variety of exposure conditions with respect to the modulation and intensity of the RF exposure using various methods of dosimetry.

In vitro research relies on experimental observations of isolated cells or tissue samples. Effects observed in vitro, however, are often difficult to correlate with any effects on human health (IEGMP 2000). In vitro research can provide insight into the mechanisms of interaction of agents on specific biological functions involving; membrane function, signal transduction pathways, biochemical reactions, genetics, cellular cycles and proliferation effects, etc.

While in vitro research investigates effects on isolated cells or tissue samples, laboratory experimentation on animals looks at similar effects in a physiologically sustained system where individual cells have support of the whole organism. As with in vitro research, however, in vivo studies do not necessarily represent or imply any clear associations of the consequences for human health. Animal studies have looked at areas such as genetic and cancer related effects, the immune system and the nervous system (WHO 1993). However, there are significant differences between animals and humans in both physiological processes and in the distribution of absorbed RF energy that occurs during exposure. Therefore, specific effects observed in animals (or in vitro studies) cannot be easily extrapolated to humans.

The most direct investigation of any potential adverse health effects comes from experimental studies on people. Research on human volunteers can disclose physiological or behavioural anomalies resulting from exposure to RF radiation. Reported effects include neurological symptoms, disturbance of sleep patterns and the integrity of the immune system and these are discussed in Annexes 3 and 4.

Radiofrequency energy is absorbed by a living organism at the molecular, cellular, tissue and whole body levels. The dielectric properties of tissue determine the net electromagnetic energy absorbed which is ultimately converted into heat via various processes.

In laboratory experiments exposure conditions can be classified into 'thermal' and 'non-thermal' levels. A significant debate has evolved over the years concerning such a classification and other terms like 'high' and 'low' level studies. It is important to note, however, that there are no strict boundaries in relation to the amount of energy absorbed and that any terminology used depends upon the mechanism of the absorbed effect (Repacholi 1998).

Experimental studies have examined a wide variety of end points including physiological and thermoregulatory responses, effects on behaviour and on the induction of lens opacities and adverse reproductive consequences resulting from exposure to relatively high levels of radiofrequency radiation (ICNIRP 1996). The majority of biological effects reported are consistent with responses to induced heating, resulting in temperature rises greater than 1°C (WHO 1993).

A number of biological effects have been reported in cell cultures and in animals, often in response to exposure to relatively low-level fields. Such effects are not well established but may have health implications and are, therefore, the subject of on-going investigations (European Commission 1996). Research into RF bio-effects at non-thermal levels is explored further in Annex 4.

The possibility of carcinogenic effects of exposure to RF fields has received considerable attention in the last 20 years. Studies have examined the possibility that RF energy may cause DNA damage or influence tumour promotion. The

balance of evidence suggests that exposure to RF fields is not mutagenic and therefore unlikely to act as an initiator or promoter of carcinogenesis (IEGMP 2000).

Epidemiological Studies

Epidemiological methods and the relevant studies are discussed in Annex 3. The epidemiological evidence does not give clear or consistent results that indicate a causal role of low intensity radiofrequency exposures in connection with any human disease. On the other hand, the results cannot establish the absence of any hazard, other than to indicate that for some situations any undetected health effects must be small (Elwood 1999). Cancer is the disease that has been studied most extensively, and although there are many individual associations seen, there is little overall consistency in the results. The studies of general populations living near radio or television transmitters relate to radiofrequency exposures likely to be well below currently accepted standards. The studies of military personnel and occupational groups may include some exposures beyond general population standards.

Of the individual studies, the general population study in the UK (Dolk et al. 1997) is sufficiently strong to reasonably exclude a geographical pattern with an excess of human cancers in subjects living close to large UHF and VHF television and radio transmitters, although there is still a possible question in regard to adult leukaemia. The Motorola employees' study (Morgan et al. 2000) is sufficiently powerful to reasonably exclude a substantial excess of leukaemia or lymphoma in about ten years from radiofrequency exposure in these workers. This time interval is not long enough to exclude an incidence effect, but it does provide substantial evidence against a short-term promotion effect, such as has been suggested by some animal experiments. The large population based study of mobile phone subscribers in Denmark (Johansen et al. 2001) also gives substantial evidence against there being any short term increases in cancer with typical levels of phone use by residential subscribers. None of these studies give good information on individual levels of exposure.

There are now three case control studies published on brain cancer in relationship to personal use of mobile phones, which show no consistent evidence of any increased risk (Hardell et al. 1999; Inskip et al. 2001; Muscat et al. 2000). One recent small study showed an increased risk of ocular melanoma, which requires validation (Stang et al. 2001).

The other epidemiological studies of radiofrequency exposures and human disease outcomes show little consistency. The results for congenital malformations and spontaneous abortions are inconsistent. The results from the Swiss studies on self-reported sleep disturbances are difficult to interpret because of the subjective nature of the outcomes assessed and the potential for recall bias. Of the human studies of exposures under experimental conditions, one study showed an increase in blood pressure after an exposure similar to mobile phone use, and this study needs replication.

Other studies are in progress, including those in the World Health Organization International EMF project: www.who.int/peh-emf.

Clinical case reports

Medical case reports of health effects arising from exposures to RF fields are useful because they provide information which cannot be ethically or easily

obtained in laboratory or other settings. Case reports often report apparently unusual occurrences in a wide variation in exposure circumstances. They are mainly useful as sources of information for a) generating new hypotheses concerned with health effects or b) confirming existing views on safety levels and mechanisms. By their nature, case reports incorporate a publication bias: they can highlight adverse effects but they do not indicate the prevalence of such effects. By themselves they do not provide a basis for setting health standards.

Cases of neurological effects, particularly dysaesthesiae (abnormal sensations), have been reported after exposure to a wide range of frequencies typically within the range from 10 MHz to 2450 MHz. In some cases symptoms are transitory but lasting in others. After very high exposures there is evidence that nerves are grossly injured, but after lower exposures resulting in dysaesthetic symptoms ordinary nerve conduction studies find no abnormality, but current perception threshold studies may. Only a small proportion of similarly exposed persons develop symptoms. The role of modulations needs clarification. Some of these observations are not consistent with the prevailing hypothesis of health effects.

Some specific case reports are summarised on www.arpansa.gov.au.

Relevance of studies to the determination of exposure limits

It is important to recognise that biological effects of RF exposure may not necessarily indicate a health hazard. Within the WHO International EMF Project, a working definition of health hazard has been developed:

> A *biological effect* is a physiological response to exposure, and
> A *health hazard* is a biological effect, outside the normal range of physiological compensation, that is detrimental to health or well-being.

Many reported biological effects which fall into the latter category are accompanied by temperature rises of several degrees and these have been used in setting some of the basic restrictions referred to below.

Although there is some data indicating that biological effects could occur in various species at exposure levels marginally below the ICNIRP Guidelines, none of the data could be used to establish that exposure within the ICNIRP Guidelines would lead to an adverse health effect in humans. Moreover, when due consideration is given to interspecies differences in physiology and the associated aspects of electromagnetic field interaction, such data does not confirm a requirement to modify the ICNIRP exposure guidelines.

There is insufficient data to establish that adverse health effects would result from low-level exposures, although it cannot be unequivocally stated that such effects do not exist (i.e. a null hypothesis can never be proven through processes of inductive logic). Furthermore, a significant proportion of the population are exposed to radiofrequency electromagnetic fields and the continued development of new and existing technologies has a potential to increase the number of persons exposed and to further diversify the nature of the fields to which persons may be exposed.

Philosophy of standard setting

The purpose of this Standard is to specify limits of exposure to electromagnetic fields within the radiofrequency range from 3 kHz to 300 GHz such that any persons exposed below the limits will be fully protected against all established adverse health effects.

As explained previously, an adverse health effect results in detectable impairment of the health of the exposed individual or of his or her offspring. A biological effect on the other hand may or may not result in an adverse health effect.

The current scientific evidence clearly indicates that there are RF exposure thresholds for the adverse health effects of heating, electro-stimulation and auditory response. The basic restrictions of this Standard are derived from these thresholds and include safety margins.

There is some debate as to whether RF causes any effects below the threshold of exposure capable of causing heating and electro-stimulation, and in particular whether any effects occur at or below the exposure levels of the limits. If any low-level RF effects occur, they are unable to be reliably detected by modern scientific methods, but a degree of uncertainty remains. The data of long term exposure is limited. It was considered that the evidence for possible low-level effects is so weak and inconsistent, that it does not provide a reason to alter the level of the limits. The limits specified in this Standard are designed to protect against known health effects and may not prevent possible or unknown low-level effects, although the safety margin within the limit may provide some protection against such low-level effects.

Furthermore, the reference levels given in this Standard are based on specific 'worst case' assumptions regarding particular exposure conditions that will lead to exposure at the level of the basic restrictions. In the majority of exposure situations, such 'worst case' exposure conditions do not apply, and thus the application of the reference levels will provide additional safety margins.

Exposure groups

This Standard defines limits for occupational exposure and limits for general public exposure. Occupational exposure generally occurs in a controlled area with the exposed persons being aware of their exposure and the hazard and controls. On the other hand the general public may not be aware of the presence or level of RF exposure. The general public includes persons from different age groups and different states of health. For some other hazards such as chemicals and ionizing radiation, there are groups within the general public which are more susceptible to health effects than others. While the scientific evidence does not suggest that any groups are more susceptible to RF effects than others at levels below the occupational limits, that possibility cannot be excluded. The choice of a two-tier system with separate limits for occupational exposure and for general public exposure is therefore considered to provide the best protection.

Children and mobile phones

In respect to the ongoing debate about possible health effects arising from use of mobile phone handsets, it has been suggested that children may be more vulnerable than adults because of their developing nervous system and greater absorption of energy in the tissues of the head (IEGMP 2000). However, there is insufficient evidence to substantiate this hypothesis. For mobile phone handsets,

the basic restriction is spatial peak SAR applicable to all individuals of different sizes including children. Schönborn, Burkhardt and Kuster (1998) have shown that, at mobile phone frequencies, there is no substantive difference in the absorption of RF energy between an adult head and the heads of children aged 3 and 7 years. Notwithstanding this, the basic restrictions given in this Standard account for different sizes and tissue properties of all individuals including children.

Research reports from Gandhi, Lazzi and Furze (1996) and others indicated that adults are likely to absorb about 10% more power than a five year old child. On theoretical grounds, an adult head should absorb greater total power than a child (by virtue of the adult's larger volume of absorption). Computer modelling by Gandhi, Lazzi and Furze (1996) indicated that the highest spatial peaks SAR levels are likely to occur in the muscle tissue of adults, but the child may have higher spatial peak levels within the brain. However, these results are disputed by Schönborn, Burkhardt and Kuster (1998) who conducted studies using anatomically correct phantoms of both child and adult heads and found no significant differences in either the total absorption or distribution of spatial peak SAR. In particular, Schönborn's group also examined the issue of possible age related differences in the dielectric properties of human tissue. They concluded that there is unlikely to be any significant difference between the tissue absorption characteristics of adults and children above one year in age. Although individual characteristics such as the geometry of the head and the thickness and dielectric properties of the various tissue types are important, it is clear that the spatial distribution of SAR depends most strongly upon the proximity and orientation of the telephone handset to the body. In conclusion, the precise distribution of energy will depend on many a number of factors including the mode of operation and the particular frequency band assigned in the country of operation.

Furthermore, the Australian Communications Authority (ACA 1999, 2001) requires mandatory testing of all new models of mobile telephones (see www.aca.gov.au/standards/emr/index.htm for details). The ACA test methodology has been conservatively designed to yield a robust maximum estimate of SAR levels within a human head and it takes account of likely variations in dielectric properties, skull size and the distribution of energy within the human head.

Foetal exposure

The exposure of pregnant women is a special case. At the level of the occupational exposure limits there is no scientific evidence that the foetus is at more risk from RF field exposure than the mother, but the data is limited. However, there is evidence that exposure to field strengths substantially above the occupational exposure limits may cause harm to the foetus. Because the pregnant woman has her physiological systems for heat regulation already under stress, it is considered that the limits for occupational exposure may not provide a sufficient safety factor. Limiting the exposure of a pregnant woman to general public limits will therefore provide an additional safety margin so as to minimise any risk from accidental exposure where the foetus could be exposed to high field strengths.

Basic Restrictions

Within this Standard the limiting values of exposure are called 'basic restrictions' and these are expressed in terms of selected quantities that closely match all known biophysical interaction mechanisms that may lead to adverse health

effects. The relevant mechanisms are electrostimulation of nerve and muscle tissue, heating and thermoelastic waves. The relevant basic restrictions and the reasons for selecting the appropriate limiting values are also explained within the ICNIRP Guidelines (ICNIRP 1998).

As shown in Table 1, the basic restrictions are:

- Instantaneous spatial peak rms current density (3 kHz–10 MHz)
- Whole body average SAR (100 kHz–6 GHz)
- Spatial peak SAR in limbs (100 kHz–6 GHz)
- Spatial peak SAR in head & torso (100 kHz–6 GHz)
- Instantaneous spatial peak SAR in head & torso (10 MHz–6 GHz)
- Spatial peak SA in the head (300 MHz–6 GHz)
- Time averaged and instantaneous power flux density (6 GHz–300 GHz)

It was not considered appropriate to modify ICNIRP specifications unless there was reasonable scientific justification for doing so.

Current density

In the frequency range 3 kHz to 10 MHz, the basic restriction of instantaneous spatial peak rms current density is designed to prevent both electrostimulation and excess heating. Electrostimulation occurs when there is a sufficiently high voltage gradient induced across a cell membrane in electrically excitable tissue to activate sufficient voltage-gated ion channels to result in the formation of an action potential. The voltage induced across a cell membrane is proportional to its reactive impedance, which in turn is inversely proportional to the applied frequency. Therefore, the effect of the electrostimulation diminishes as frequency increases. At approximately 100 kHz the perceived effect of heating, caused by current induced by absorption (SAR heating) becomes more significant than electrostimulation. In the region between 100 kHz and 10 MHz, protection is required for both electrostimulation and SAR heating effects. However, at frequencies above 10 MHz, the SAR heating effect completely predominates and becomes the effect which occurs at the lowest absorbed power level and is therefore the limiting value for basic restrictions in the standard.

To establish the thresholds from which this standard is derived, the original basis for the ICNIRP thresholds was reviewed. The ICNIRP thresholds were initially derived from research documented by the World Health Organization (WHO 1993). For occupational exposure, the safety factor for current density (J) is 100. For general public exposure, the safety factor is deliberately increased by a factor of 5, becoming 500 for current density. These factors have to account for uncertainties arising from individual variation within the population or variations in local conditions of exposure or measurement. These requirements are considered to be more than adequately met by the existing safety factors. Furthermore, the limits for protection against electrostimulation provide a high degree of protection against any possible heating effects as discussed in the following parts of this schedule.

Whole body average (WBA) SAR

Radiofrequency exposure can induce currents inside the body, either by the movement of ions or by the rotation of polar molecules. The kinetic energy thus made available is dissipated as heat which adds to any endogenous heat produced by the body and adds to the burden on the intrinsic tissue cooling mechanism.

The amount of heat stored in the body depends on the balance between heat generated and heat lost. The usual limiting value of deep body temperature is about 38 ºC above which sweating and other mechanisms, which facilitate heat loss, will saturate. Throughout the development of radiofrequency standards during the last 30 years it has been accepted that a healthy adult can accommodate an additional SAR heat load of at least 4W/kg averaged over the whole body without incurring a significant increase in core body temperature. For comparison it is noted that the human basal metabolic rate (BMR) may fall as low as 1W/kg at rest or rise to up to 16W/kg during heavy exercise.

In establishing SAR basic restriction limits for whole body exposure, the restriction of 0.4W/kg has been set and has become an established benchmark. This was originally intended to represent a factor of 10 below 4W/kg. Adair et al. (1999) studied 7 sedentary fit volunteers, non-uniformly exposed over 36% of their body surface for 45 minutes to 450 MHz and later 2400 MHz CW RF fields at a predicted WBA SAR level of up to 0.9 W/kg. The peak surface SAR was estimated to be 7.7 W/kg. It was found that this exposure did not produce a significant core body temperature rise due to the response of their thermal homeostatic mechanisms. However, it was observed that sweating had not yet reached equilibrium by the end of the exposure period. On the other hand, several studies using monkeys showed no significant rise of core temperature after 90 minutes exposure at WBA SAR levels of 9 W/kg and equilibrium of their sweating response (Adair, Adams & Hartman 1992), although monkeys have substantially lower sweat rates than humans (Heaps & Constable 1995). After extensively reviewing the relevant literature, ICNIRP concluded that levels above 4 W/kg are required to overwhelm the thermoregulatory capacity of the body. Thus, the WBA SAR of 0.4 W/kg remains well supported for occupational exposure and arguably safe for the entire population. However, the existing practice of providing a further safety factor of 5 for continuous exposure to the general public remains supported in the 1998 ICNIRP Guidelines and is carried over into this Standard as a means of providing an adequate factor of safety between the standard and the onset of any detectable heating effects.

The scientific literature has on many occasions considered the possibility that RF could cause adverse effects by mechanisms other than electrostimulation or heating, including possible effects on cell membranes, and also by other unknown mechanisms. The existence of this literature is acknowledged and has been reviewed, however data from it is unsuitable for use in standards setting. However, it is reasonable to hypothesise that any effects of unknown mechanism would be related to energy transfer by the mechanisms of absorption which are understood and quantifiable and for which this standard provides limits. Therefore, the only residual concern is the possibility of effects of an unknown mechanism occurring at levels below the thresholds for electrostimulation or SAR heating, which might not therefore be afforded the same factor of protection as those intended by the standard in respect of the established mechanisms of tissue interaction. However, it is considered that the large safety factors which are applied, together with the absence of any confirmation of any other low-level mechanisms provide support for the ICNIRP basic restrictions giving adequate protection against any established or conceivable hazard.

Spatial Peak SAR

The absorption of RF energy is generally non-uniform. Under plane wave exposure conditions, calculations and measurements have indicated that spatial peak SAR in some regions of the body are up to 20 – 25 times higher than the WBA SAR (IEEE 1999; and National Radiological Protection Board [NRPB] 1993; Kitchen 1993). Also, sources close to the body produce highly localised exposure

resulting in localised absorption restricted to specific regions of the body. It is therefore necessary to consider localised heating effects (ICNIRP 1996; NRPB 1993). Basic restrictions for spatial peak SAR are therefore formulated to prevent excessive local heating of tissue and are additional to the basic restrictions for WBA SAR.

Substantial protein denaturation begins to occur at temperatures above 45°C. Mammalian cells begin to die if their temperature rises to 43°C for 23 minutes, and most mammalian cells die immediately after being elevated to 45°C (Harisiadis et al. 1975). For many years it has been known that, even during moderate exercise, muscle temperatures may rise to 39°C or more (Assmussen and Bøje 1945). Thus it is considered that a 1 – 2°C rise in local temperature resulting from environmental loads such as RF energy is unlikely to cause ill effects.

The ability to cope with heat stress varies with different organs and tissues. The limbs and outer layers of the body are better adapted to tolerate higher temperature fluctuations in order to cope with wide changes in environmental conditions. In contrast internal organs are less tolerant of large deviations from core body temperature. The brain and eye require particular attention.

The temperature of the brain and other major organs is normally closely aligned with core body temperature. This varies between individuals but is usually around 37 °C. In sitting, healthy men the oral temperature (0.2 – 0.5 °C below core temperature) ranges from 36.4 °C to 37.2 °C (Leithead & Lind 1964). Some factors such as circadian variation and cyclical variation in women cause small variations in core temperature within the individual (Adair et al. 1998). Homeostatic mechanisms within the body normally minimise the effect on core temperature of other factors such as vigorous exercise in, variations in ambient temperature, sequelae of food intake and emotional factors (Montain, Latzke & Sawka 2000).

Any disease that can interfere with the body's thermoregulatory system, such as multiple sclerosis, may make that individual more sensitive to the effects of environmental heat stress (Henke, Cohle, & Cottingham 2000). Some medications may also decrease the homeostatic capacity of the individual (Hermesh et al. 2000). Central nervous system function deteriorates at temperatures above 41 – 42°C where heat stroke may occur. It has been estimated (Anderson & Joyner 1995; van Leeuwen et al. 1999; NRPB 1993; Wainwright 2000) that a prolonged SAR exposure at the spatial peak basic restriction for the general public (2 W/kg) may increase local tissue temperature in a small region of the brain by about 0.1°C. Corresponding estimates of the maximum temperature rise for the occupational limit (10 W/kg) are in the range of 0.5 – 0.8 °C. Such estimates do not include thermoregulatory responses (e.g. vasodilation) which would be expected to enhance the body's ability to dissipate heat.

The eye has traditionally been recognised as an especially vulnerable organ. Denaturation of protein crystals in the lens of the eye at sustained elevated temperatures above 43°C (Carpenter & Van Ummersen 1968) has been linked with induction of cataracts. The cataractogenic threshold has been determined by the NRPB (1993) to be about 100 W/kg (based on short term animal studies), and so the 10 W/kg occupational spatial peak SAR limit provides a factor of safety of 10 and the 2 W/kg for general public exposure provides a safety factor of 50. However, with respect to chronic exposure the NRPB (1993) states 'The threshold

for cataract induction resulting from chronic exposure of RF radiation has not been defined'.

Limbs

The extremities of the body are better adapted and more tolerant of temperature variations than are the eyes and brain. Spatial peak SAR limits for the extremities have therefore been set at a level double that of the head and torso. The adequacy of this limit has been confirmed by computer modelling and experiments on human volunteers (NRPB 1993; Sienkiewicz et al. 1989)

Power Flux Density

Between 6 GHz and 300 GHz, basic restrictions are provided on power flux density to prevent excessive heating in tissue at or near the body surface. At such frequencies the depth of penetration in tissue is relatively short (less than 8 mm) and surface heating is the predominant effect. Therefore, power flux density is a more appropriate metric (NRPB 1993; IEEE 1999)

Amplitude and Pulse Modulation

Relevant literature since the publication of the 1998 ICNIRP Guidelines has been reviewed. Such literature is in agreement with ICNIRP's conclusion that 'Overall, the literature on athermal effects of amplitude modulated electromagnetic fields is so complex, the validity of reported effects so poorly established, and the relevance of the effects to human health is so uncertain, that it is impossible to use this body of information as a basis for setting limits on human exposure to these fields' (ICNIRP 1998).

However, this Standard introduces a new basic restriction, 'instantaneous spatial peak SAR', which provides a mandatory basis for the instantaneous E and H reference levels.

Furthermore, nuisance auditory effects (Lin 1978; Lin 1990; Heynick & Polson 1996) are known to be associated with exposure to extremely high peak power short pulse systems (e.g. military radar). Accordingly, to prevent such nuisance auditory effects, a basic restriction is defined to limit specific absorption (SA) in the head within the frequency range from 300 MHz to 6 GHz. In addition to the basic restriction for instantaneous spatial peak SAR, the SA restriction also serves to prevent unknown but possible adverse effects that might be associated with exposure to pulsed RF fields from extreme high peak power pulsed systems.

Reference levels

The basic restrictions were based on the need to provide protection against established adverse health effects. Compliance with the limits recommended in this Standard will ensure that persons exposed to RF fields are protected against all known adverse health effects.

The 'basic restrictions' are closely related to biological parameters internal to the human body. In many situations, the direct measurement of a basic restriction, is often impractical or beyond the technical capability of those wishing to determine compliance. In such circumstances, practical or 'surrogate' parameters must be provided as an alternative to the 'basic restrictions'. Therefore an alternative set of indicative limits known as 'reference levels' have been provided as a means for determining compliance (see clauses 2.2, 2.4).

As shown in Table 1 of Section 2 and in Figures 1 and 2, depending on the frequency range and the type of basic restriction, reference levels are provided in terms of electric and magnetic field strength, power flux density, induced limb currents and point contact currents. The reference levels have been conservatively formulated and for most exposure situations they will provide a significant increase in safety margins above those provided by the basic restrictions. The reference levels have been derived on the basis that there is maximum coupling of the field to the exposed individual, consequently they offer maximum protection for such 'worst case' exposure situations.

For frequencies within the range 10 MHz to 400 MHz absorption will be greatest if the wavelength of the incident wave and the receiving body are of corresponding dimensions or at resonance. For an average adult, in the far-field of a linearly polarised wave, the maximum resonance absorption occurs with the body parallel to the electric field vector at a frequency of about 70 MHz for 'free space' exposure conditions. For an adult standing on a ground plane the resonant frequency will be about 35 MHz. For frequencies above the whole body resonance region, there is less penetration of tissue and increased reflection. Such factors are taken into account by defining a constant maximum level of protection over approximately two octaves either side of resonance. At the lower limit there is transition into the area below 10 MHz where induced current effects become significant. Accordingly, additional basic restrictions are defined in terms of induced current density. At frequencies above 400 MHz, relaxation of the reference levels is allowed in line with decreased absorption. Such that the reference level is linearly increased with frequency, as given by the formula $f/200$ W/m^2 (f in MHz). This approach is terminated when internal absorption reduces to the point where surface heating becomes the predominant effect. At frequencies above 4 GHz total absorption is no longer frequency dependent and the magnitude of the reference level remains constant.

Measurement Averaging Considerations

The adequacy of basic restrictions and associated reference levels depend upon the proper selection and specification of both temporal and spatial measurement conditions. For a given biological effect it is important that the characteristics of the interaction mechanisms are thoroughly and adequately accounted for. In particular, it is necessary to specify appropriate measurement conditions applicable to the quantitative limit values. In this respect, it is essential that measurements are performed within an appropriate averaging volume (or tissue mass) and within a time period that is shorter than, or closely matched to, fundamental injury processes.

During very close proximity exposure to low frequency high power radiators, contact or arc-over currents can produce RF shock and related burns. Such effects usually occur within very brief time intervals. While electrostimulation of excitable tissue is the major concern for frequencies below 100 kHz, rapid heating of tissue is the predominant effect for frequencies above 100 kHz. For this reason, the averaging times used for low frequency (under 10 MHz) current effects are selected to be as short as practical and consistent with relevant interaction mechanisms (refer note 2 of Table 9, also note 3 of Table 8 and note 3 of Table 5). Similarly, to prevent unwanted auditory effects associated with pulsed fields, an averaging time of 50 microseconds is specified for determination of spatial peak SA pulse exposure to the head.

Spatial averaging volumes for both spatial peak SAR within the body and SA within the head are restricted to 10 gram of tissue mass on the basis that this is marginally less than the smallest tissue volume over which a thermal effect is likely to occur.

For exposure to frequencies above a few MHz, SAR is clearly an appropriate quantity for evaluating likely heating effects on internal organs. However, at extremely high frequencies the RF energy is absorbed near the skin within a few millimetres of surface and the basic restriction is more appropriately defined in terms of power flux density. The required measurement averaging volume for spatial peak SAR is 10 g of contiguous tissue in the shape of a cube. Hence, the corresponding side length of a spatial peak SAR measurement cube will be about 2 centimetres (depending on tissue density). However, for exposure to frequencies above 6 GHz, most of the absorbed energy is deposited near the skin within a centimetre of the surface and a spatial peak SAR measurement would not be indicative of the highly localised heating. Accordingly, a 6 GHz maximum cut-off frequency was chosen for SAR measurements (this differs from the 10 GHz specified by ICNIRP). This approach is consistent with known interaction processes and for frequencies between 6 GHz and 10 GHz it ensures a greater safety margin than the ICNIRP 1998 guidelines.

Far-field exposure situations at frequencies below 10 GHz generally involve relatively large 'hot spots' where the heat load on the whole body is the major constraint. In such circumstances, a measurement averaging time of around six minutes is adequate. However, at high frequencies, absorption of RF energy is restricted to relatively small volumes of tissue near to the surface of the body. In such circumstances, heating of skin can be quite rapid and progressively short measurement averaging times (seconds rather than minutes) are invoked for measurement of power flux density at frequencies above 10 GHz.

Earlier versions of AS 2772 part 1 clearly show an intention to maintain reference levels in accord with a WBA SAR of 0.4 W/kg. The reference levels for E and H fields and power flux density in those earlier standards were maintained at a constant value for all frequencies above 400 MHz. However, at frequencies above 400 MHz, such reference levels were not in accord with established dosimetry data. The reason for such reference levels in the prior standards is not clearly explained in relevant rationale statements. However, the 1990 version of AS 2772.1 provides the following statement:

> 'In the hot spot range it had been noticed that several standards and proposals have an increase in maximum exposure level from 1 mW/cM^2 [sic.] to a value of 5 mW/cm^2 or 10 mW/cm^2, this increase commencing at different frequencies (e.g. C-V model at 130 MHz, ANSI at 300 MHz IRPA at 400 MHz, Canada (7) at 1 GHz, ACGIH at 100 MHz, NRPB at 100 MHz for adults and 300 MHz for general populations). However, WHO has referred to reports of corneal damage and epithelial and stromal injury to the eyes of rabbits when exposed to 35 GHz and 107 GHz radiation at power flux densities ranging from 5 mW/cm^2 to 60 mW/cm^2 for 15 min. to 1 h. Although these effects have not been reported in man, there is a possibility that they could occur after long periods of exposure. Accordingly, the committee agreed that, with the present state of knowledge and taking into account the differences in opinion as to where an increase in the maximum exposure level would be appropriate, it would not be wise to increase the maximum exposure level for this frequency range above 1 mW/cm^2 at the present time.' (Standards Australia 1990).

Clearly the relevant committee was concerned about the effect of very high frequencies. In this context, it is significant that at frequencies of 35 GHz and 107 GHz, the corresponding 1/e penetration depth for skin is very small (0.75 mm and 0.35 mm respectively). The averaging times specified in the prior AS 2772.1 standards were between one and six minutes (depending on year of publication). Under certain circumstances, the six minute averaging time employed may have been too long to prevent injury. For example, rapid heating may occur during exposure to high level transients of a few seconds duration. In contrast, this Standard allows an increase in the magnitude of the reference levels for frequencies above 400 MHz up to 2 GHz. At frequencies above 2 GHz the reference levels are held constant. In particular, this Standard mandates a decreasing averaging time for frequencies above 10 GHz ranging from 6 minutes at 10 GHz down to 10.2 seconds at 300 GHz.

In summary, in addition to limiting the magnitude of relevant exposure parameters, this Standard employs appropriate formulation of spatial and temporal measurement parameters to ensure that adequate protection is maintained. Clause 2.7 also provides an appropriate methodology for spatial assessment of reference levels.

References and Bibliography

Adair, E. R., Cobb B. L., Mylacraine, K. S. & Kelleher, S. A. 1999, 'Human exposure at two radio frequencies (450 and 2450 MHz): similarities and differences in physiological response', *Bioelectromagnetics*, vol. 20, pp. 12-20.

Adair, E. R., Kelleher, S. A., Mack, G. W. & Morocco, T. S. 1998, 'Thermophysiological responses of human volunteers during controlled whole-body radio frequency exposure at 450 MHz', *Bioelectromagnetics,* vol. 19, pp. 232-245.

Adair, E. R., Adams, B. W. & Hartman, S. K. 1992, 'Physiological interaction processes and radiofrequency energy absorption', *Bioelectromagnetics*, vol. 13, pp. 497-512.

Adair, E. R., Adams, B. W. 1980, 'Microwaves modify thermoregulatory behaviour in squirrel monkey', *Bioelectromagnetics*, vol. 1, pp. 1-20.

Adair, E. R., Adams, B. W., Akel G. M. 1984, 'Minimal changes in hypothalamic temperature accompany microwave-induced alteration of thermoregulatory behaviour', *Bioelectromagnetics*, vol. 5, pp. 13-30.

Assmussen, E. & Bøje, O. 1945. Body temperature and capacity for work. *Acta Physiol Scand,* vol. 10, no. 1.

ANSI 1966, *Safety Level of Electromagnetic Radiation with Respect to Personnel*, The Institute of Electrical and Electronic Engineers, New York USA.

ANSI 1982, *Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz*, The Institute of Electrical and Electronic Engineers, New York USA.

Australian Communications Authority (ACA) 1999*, Radiocomunications (Electromagnetic Radiation — Human Exposure) Standard*, Australian Communications Authority, Canberra Australia.

Australian Communications Authority (ACA) 2001*, Radiocomunications (Electromagnetic Radiation — Human Exposure) Standard*, Australian Communications Authority, Canberra Australia.
[Refer www.aca.gov.au/standards/emr/index.htm for additional information]

Anderson V. & Joyner, K. H. 1995, 'Specific absorption rate levels measured in a phantom head exposed to radio frequency transmissions from analog hand-held mobile phones', *Bioelectromagnetics*, vol. 16, no. 1, pp. 60-69.

Byczynski, A. Z. 1960, *Health hazards of microwave radiation*, Radio design note no. 2 / 1960, Postmaster-General's Department, Commonwealth of Australia.

Carpenter R. L. & Van Ummersen C. A. 1968, 'The action of microwave radiation on the eye' *Journal of Microwave Power,* vol. 3 no. 1, pp. 3-19.

Christie, R. V. 1928, 'An Experimental Study of Diathermy'.

Cornelius W. A. & Viglione G. 1979, *Recommended permissible levels for exposure to microwave and radiofrequency radiation (10 MHz to 300 GHz) - A proposal*, Australian Radiation Laboratory Technical Report ARL/TR 009, Yallambie Australia. [ISSN 0517-1400].

Council of the European Union 1999, 'Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz)', *Official Journal*, issue L 199, pp. 0059 – 0070.

de Lorge, J.; Ezell, C.S. 'Observing-responses of rats exposed to 1.28- and 5.62-GHz microwaves', *Bioelectromagnetics*, vol. 1, pp. 183-198.

Dolk, H., Elliott, P., Shaddick, G., Walls, P. & Thakrar, B. 1997, 'Cancer incidence near radio and television transmitters in Great Britain 2: All high power transmitters', *American Journal of Epidemiology*, vol. 145, pp. 10-17.

Elwood, J. M. 1999, 'A critical review of epidemiologic studies of radiofrequency exposure and human cancers', *Environmental Health Perspectives*, vol. 107, pp. 155-168.

Franke V.A. 1961, 'Calculations of the absorption of energy from an electromagnetic field by means of semiconductor models resembling the human body'. *Collection of Scientific Papers of the VCSPS Institute of Industrial Safety: Leningrad*, vol. 3, pp. 36-45.

European Commission (EC) 1996, *Possible Health Effects Related to the Use of Radiotelephones*, Proposals for a Research Programme by a European Commission Expert Group, European Commission, Brussels.

Gandhi, O.P. 1974, 'Polarization and frequency effects on whole animal absorption of RF energy'. *Proceedings of the IEEE,* vol. 62, pp. 1171-1175.

Gandhi O.P. 1975, 'Frequency and orientation effect on whole animal absorption of electromagnetic waves'. *IEEE Transcripts of Biomedical Engineering*, BME-22, pp. 536-542.

Gandhi, O.P. 1979, 'Dosimetry - the absorption properties of man and experimental animals', *Bulletin of the New York Academy of Med*icine, vol. 55, pp. 990-1020.

Gandhi, O.P. 1980, 'State of the knowledge of electromagnetic absorbed dose in man and animals', Proceedings of the IEEE, vol. 68, pp. 24-32.

Gandhi, O.P., Lazzi, G. & Furze, C. M. 1996, 'Electromagnetic absorption in the human head and neck for mobile telephones at 835 and 1900 MHz', *IEEE Transactions on Microwave Theory and Techniques*, vol. 44, pp. 1884-1897.

Guy, A. W. L., Lin, J. C., Kramar, P. O. & Emery, A. 1975, 'Effect on 2450-MHz radiation on the rabbit eye'. *IEEE Transactions on Microwave Theory and Techniques*, vol. 23, pp. 492-498.

Hackmann, W. 1994, 'Making Waves', *Nature,* vol. 372, pp. 628-629.

Hardell, L., Näsman, Å., Påhlson, A., Hallquist, A. & Mild, K.H. 1999, 'Use of cellular telephones and the risk for brain tumours: a case-control study', *International Journal of Oncology*, vol. 15, pp. 113-116.

Harisiadis L., Hall E.J., Kraljevic U. & Borek C. 1975, 'Hyperthermia: biological studies at the cellular level' *Radiology*, vol. 117, no. 2, pp. 447-52.

Heaps, C.L. & Constable, S.H. 1995, 'Physiological responses of rhesus monkeys to exercise at varied temperatures', *Aviation Space and Environmental Medicine*, vol. 66, no. 2, pp. 137-142.

Henke, A., Cohle, S. & Cottingham, S. 2000, 'Fatal hyperthermia secondary to sunbathing in a patient with multiple sclerosis', *American Journal of Forensic & Medical Pathology* vol. 21, no. 3, pp. 204-206.

Hermesh, H., Shiloh, R., Epstein, Y., Manaim, H., Weizman, A. & Munitz, H. 2000. 'Heat intolerance in patients with chronic schizophrenia maintained on antipsychotic drugs', *American Journal of Psychiatry,* vol. 157, pp. 1327-1329.

Heynick L.N. & Polson P. 1996, *Human exposure to radiofrequency radiation: A comprehensive review of the literature pertinent to air force operations*, United States Air Force Research Laboratory Technical Report AL/OE-TR-1996-0035, Brooks Air Force Base, Texas USA.
[Refer www.brooks.af.mil/AFRL/HED/hedr/reports/]

Hocking, B. 1981, *Occupational Health Policy and Guidelines – Radiofrequency (0.3–300,000 MHz) Safety Standards*, Telecom Australia Guideline No 11.1, Telecom Australia.

ICNIRP 1998, 'Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)', *Health Phy*sics, vol. 74, no. 4, pp. 494-522.

ICNIRP 1996, 'Health issues related to the use of hand-held radiotelephones and base transmitters', *Health Physics*, vol. 70, no. 4, pp. 587-593.

IEEE 1992, *Standard for Safety Levels with Respect to Human Exposure to Radiofrequency Electromagnetic Fields, 3 kHz to 300 GHz*, IEEE C95.1-1991, The Institute of Electrical and Electronic Engineers, New York USA.

IEEE 1999, *IEEE Standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz*, IEEE Std C95.1, The Institute of Electrical and Electronic Engineers, New York USA.

Independent Expert Group on Mobile Phones 2000, *Mobile phones and health* (Sir William Stewart, Chairman), National Radiological Protection Board, Chilton, Didcot, UK.
[Refer www.iegmp.org.uk]

Inskip, P. D., Tarone, R. E., Hatch, E. E., Wilcosky, T. C., Shapiro, W. R., Selker, R. G., Fine, H. A., Black, P. M., Loeffler, J. S. & Linet, M. S. 2001, 'Cellular-telephone use and brain tumors', *New England Journal of Medicine*, vol. 344, pp. 79-86.

Johansen, C., Boice, J. D. Jr, McLaughlin, J. K. & Olsen, J. H. 2001, 'Cellular telephones and cancer - a nationwide cohort study in Denmark*, Journal of the National Cancer Institute*, vol. 93, pp. 203-207.

Johnson, C. C. & Guy, A. W. 1983, 'Nonionizing Electromagnetic Wave effects in Biological Materials and Systems' in *Biological Effects of Electromagnetic Radiation*, ed. J. M. Osepchuk, IEEE Press, New York USA, pp. 47-73.

Kitchen, R. 1993, *The RF Radiation Safety Handbook*, Butterworth-Heinemann Ltd. [ISBN 0750617128]

Kues, H. A., Hirst, L. W., Lutty, G. A., D'Anna, S. A., Dunkelberger, G. R. 1985, 'Effects of 2.45-GHz microwaves on primate corneal endothelium', *Bioelectromagnetics*, vol. 6, pp. 177-188.

Kloth, L., Morrison, M. A. & Ferguson, B. H. 1984, *Therapeutic microwave and shortwave diathermy — A review of thermal effectiveness, safe use and state of the art: 1984*, United States Department of Public Health and Human Services, Center for Devices and Radiological Health, Rockville, Maryland USA.

Lange, V. W. 1976, *Standards for exposure to HF Radiation (3–30 MHz)*, exposure guideline, file ref: 72/2396, Radio Australia.

Leithead, C. & Lind, A. 1964, *Heat stress and heat disorders*, Cassell, London.

Lin, J. C., 1978, *Microwave auditory effects and applications*, C.C. Thomas, Springfield, Illinois USA. [ISBN 0-398-03704-3]

Lin, J.C., 1990, 'Auditory perception of pulsed microwave radiation' in *Biological Effects and Medical Applications of Electromagnetic Fields*, ed. O.P. Gandhi, Prentice-Hall, New York USA, Chapter 12, pp. 277-318.

Lords, J. L., Neilson, H. C. 1986, 'Behavioral and physiological effects of chronic 2450-MHz microwave irradiation of the rat at 0.5 mW/cm2', *Bioelectromagnetics*, vol. 7, pp. 45-56.

Michaelson S.M. 1983, 'Biological effects and dosimetry of non-ionizing radiation, in Biological effects and health hazards of RF and MW energy: fundamentals and overall phenomenology', Grandolfo, M. M., Michaelson, S.M., Rindi A., Editor, *Plenum Press*, New York, pp. 337-357.

Michaelson, S. M. E., E. C. 1996, 'Modulated fields and 'window' effects., in Biological effects of electromagnetic fields', C.P. Polk, E., Editor. 1996, *CRC Press*: Boca Raton, FL, pp. 435-533.

Mild, K. H., Oftedal, G., Sandstrom, M., *et al.* 1998, 'Comparison of symptoms experienced by users of analogue and digital mobile phones; a Swedish-Norwegian study', *Investigation report No 1998:23*, National Institute of Working Life, Solna, Sweden, 1998. [ISSN 1401-2928].

Montain, S., Latzka, W. & Sawka, M. 2000 'Impact of muscle injury and accompanying inflammatory response on thermoregulation during exercise in the heat', *Journal of Applied Physiology,* vol. 89, no. pp. 1123-1130.

Morgan, R. W., Kelsh, M.A., Zhao, K., Exuzides, K.A., Heringer, S. & Negrete W. 2000, 'Radiofrequency exposure and mortality from cancer of the brain and lymphatic/hematopoietic systems', *Epidemiology,* vol. 11, pp. 118-127.

Moulder, J. E., Erdreich, L. S., Malyapa, R. S., Merritt, J., Pickard, W. F., Vijayalaxmi 1999, 'Cell phones and cancer: what is the evidence for a connection?', *Radiation Research*, vol. 151, no. 5, pp. 513-531.

Muscat, J. E., Malkin, M. G., Thompson, S., Shore, R., Stellman, S., McRee, D., Neugut, A. I. & Wynder, E. L. 2000, 'Handheld cellular telephone use and risk of brain cancer', *JAMA*, vol. 284, pp. 3001-3007.

Mumford, W. W. 1961, 'Some technical aspects of microwave radiation hazards', *Proceedings of the IRE*, Vol. 49, pp.427-447.

National Council on Radiation Protection and Measurements (NCRP), 1993 'A Practical Guide to the Determination of Human Exposure to Radiofrequency Fields,' *NCRP,* Report No. 119, 1993, Bethesda, MD 20814.

National Radiological Protection Board (NRPB) 1993, *Board statement on restrictions on human exposure to time static and varying electromagnetic fields and radiation,* Documents of the NRPB, vol. 4, no. 5, National Radiological Protection Board, Chilton, Didcot UK.
[Refer www.nrpb.org/publications/documents_of_nrpb]

Oftedal, G., Wilen, J., Sandstrom, M., Mild, K. H. 2000 'Symptoms experienced in connection with mobile phone use', *Occupational Medicine* (London), May, vol. 50, no. 4, pp. 237-245.

Poltev, M. K. 1985, 'Occupational Health and Safety in Manufacturing Industries', *Mier Publishers*, Moscow, p. 143 (Table 20).

Presman, A. S. 1968, 'Electromagnetic fields and animate nature', *USSR Academy of Science*, Moscow.

Reeves, G. I. 2000 'Review of extensive workups of 34 patients overexposed to radiofrequency radiation' *Aviat Space Environ Med,* Mar, vol. 71, no. 3, pp. 206-215.

Repacholi, M. H. 1998, 'Low level exposure to radiofrequency electromagnetic fields: health effects and research needs', *Bioelectromagnetic*s, vol. 19, p. 1.

Royal Society of Canada 1999, *A review of the potential health risks of radiofrequency fields from wireless telecommunication devices,* An Expert Panel Report prepared at the request of the Royal Society of Canada for Health Canada, RSC.EPR 99-1, Royal Society of Canada, Ottawa Canada.

Schönborn, F., Burkhardt, M. & Kuster, N. 1998, 'Differences in energy absorption between heads of adults and children in the near-field of sources', *Health Physics*, vol. 44, no. 10, pp. 1884-1897.

Schwan, H. P. & Piersol, G.M. 1954, 'The absorption of electromagnetic energy in body tissues. Part I. Biological aspects', *American Journal of Physical Medicine*, vol. 33, pp. 370-404.

Schwan, H. P. & Peirsol, G. M. 1955, 'The absorption of electromagnetic energy in body tissues. Part II. Physiological and clinical aspects', *American Journal of Physical Medicine*, vol. 34, pp. 425-448.

Sienkiewicz, Z. J., O'Hagan, J. B., Muirhead, C. R. & Pearson, A. J. 1989, 'Relationship between local temperature and heat transfer through the hand and wrist', *Bioelectromagnetics*, vol. 10, no. 1, pp. 77-84.

Standards Association of Australia 1972, *Radio transmitters and similar equipment – Safe practices*, AS 1188–1972, Standards Association of Australia, Sydney Australia.

Standards Association of Australia 1985, *Maximum exposure levels – Radiofrequency radiation – 300 kHz to 300 GHz*, AS 2772–1985, Standards Association of Australia, Sydney Australia.

Standards Australia 1990, *Radiofrequency radiation, Part 1: Maximum exposure levels – 100 kHz to 300 GHz*, AS 2772.1-1990, Standards Australia, Sydney Australia.

Standards Australia/Standards New Zealand 1998, *Radiofrequency fields. Part 1: Maximum exposure levels—3kHz to 300 GHz*, AS/NZS 2772.1(Int), Standards Australia, Sydney Australia.

Standards New Zealand 1999, *Radiofrequency Fields, Part 1 – Maximum Exposure Levels – 3kHz to 300 GHz*, NZS 2772: Part1: 1999, Standards New Zealand, Wellington New Zealand.

Stang, A., Anastassiou, G., Ahrens, W., Bromen, K., Bornfeld, N. & Jockel, K. H. 2001, 'The possible role of radiofrequency radiation in the development of uveal melanoma', *Epidemiology*, vol. 12, pp. 7-12.

Telecom Australia 1975, *Internal Memorandum*, Report 74/76, January.

Tell, R. A. 1978, *An analysis of radiofrequency and microwave absorption data with consideration of thermal safety standards*, Report No ORP/EAD, Office of Radiation Protection Programs, Environmental Protection Agency, Las Vegas, Nevada USA.

van Leeuwen, G. M. J., Lagendijk J. J. W, van Leersum B. J. A. M, Zwamborn A. P. M., Hornsleth S. N. & Kotte A. N. T. J. 1999, 'Calculation of change in brain temperatures due to exposure to a mobile phone' *Physics in Medicine & Biology*, vol. 44, pp. 2367-2379.

Wainwright, P. 2000, 'Thermal effects of radiation from cellular telephones' *Physics in Medicine and Biology*, vol. 45, pp. 2363-2372.

World Health Organization (WHO) 1993 *Electromagnetic fields (300 Hz to 300 GHz)*, Environmental Health Criteria No. 137, United Nations Environment Programme/International Radiation Protection Association/World Health Organization, Geneva Switzerland.

World Health Organization (WHO) 2000, 'Electromagnetic fields and public health: Mobile telephones and their base stations', *Fact Sheet No. 193*, Geneva Switzerland.

World Trade Organization 1994, *Agreement on Technical Barriers to Trade 1994*, World Trade Organization, Geneva Switzerland.
[Refer www.wto.org/english/tratop_e/tbt_e/tbtagr.htm]
(See Article 2 Technical Regulations and Standards, and Annex 3 Code of good practice for the preparation, adoption and application of standards.)

Schedule 2
Look-up Table of Reference Levels for Occupational Exposure to Electric and Magnetic Fields as Specified in Table 7 and Table 8

Frequency		E-field strength (V/m rms)		H-field strength (A/m rms)		Equivalent plane wave power flux density S_{eq} (W/m²)	
		Time Average From Table 7	Instantaneous from Table 8	Time Average from Table 7	Instantaneous from Table 8	Time Average from Table 7	Instantaneous from Table 8
3	KHz	–	614	–	25.0	–	–
10	KHz	–	614	–	25.0	–	–
65	KHz	–	614	–	25.0	–	–
70	KHz	–	614	–	23.3	–	–
80	KHz	–	614	–	20.4	–	–
90	KHz	–	614	–	18.1	–	–
100	KHz	614	614	16.3	16.3	–	–
120	KHz	614	704	13.6	15.6	–	–
150	KHz	614	832	10.9	14.7	–	–
200	KHz	614	1032	8.15	13.7	–	–
300	KHz	614	1399	5.43	12.4	–	–
400	KHz	614	1736	4.08	11.5	–	–
500	KHz	614	2053	3.26	10.9	–	–
600	KHz	614	2353	2.72	10.4	–	–
700	KHz	614	2642	2.33	10.0	–	–
800	KHz	614	2920	2.04	9.69	–	–
900	KHz	614	3190	1.81	9.40	–	–
1	MHz	614	3452	1.63	9.16	1001	31620
1.5	MHz	409	3119	1.09	8.28	445	25818
2	MHz	307	2903	0.815	7.70	250	22359
3	MHz	205	2623	0.543	6.96	111	18256
4	MHz	154	2441	0.408	6.48	62.6	15810
5	MHz	123	2308	0.326	6.13	40.0	14141
6	MHz	102	2206	0.272	5.85	27.8	12909
7	MHz	87.7	2122	0.233	5.63	20.4	11951
8	MHz	76.8	2053	0.204	5.45	15.6	11179
9	MHz	68.2	1993	0.181	5.29	12.4	10540
10	MHz	61.4	1941	0.163	5.15	10.0	10000
100	MHz	61.4	1941	0.163	5.15	10.0	10000
400	MHz	61.4	1941	0.163	5.15	10.0	10000
500	MHz	68.6	2169	0.182	5.77	12.5	12500
600	MHz	75.2	2376	0.199	6.32	15.0	15000
700	MHz	81.2	2566	0.215	6.83	17.5	17500
800	MHz	86.8	2744	0.230	7.30	20.0	20000
900	MHz	92.1	2910	0.244	7.74	22.5	22500
1	GHz	97.1	3067	0.257	8.16	25.0	25000
1.5	GHz	119	3757	0.315	10.0	37.5	37500
1.8	GHz	130	4115	0.345	10.9	45.0	45000
2	GHz	137	4340	0.364	11.5	50.0	50000
10	GHz	137	4340	0.364	11.5	50.0	50000
100	GHz	137	4340	0.364	11.5	50.0	50000
300	GHz	137	4340	0.364	11.5	50.0	50000

NOTE: Occupational E and H reference levels are given in plane wave ratio at frequencies greater than or equal to 1 MHz. However, for many industrial exposure situations, equivalent plane wave power flux density is not an appropriate metric if 'far-field' exposure conditions do not apply. Survey meters may be calibrated in terms of W/m², but both E and H will generally require independent measurement and evaluation if measured in the near-field (refer Schedule 4). Appropriate conversion factors are given in Table A2 of Annex 1.

Schedule 3
Look-up Table of Reference Levels for General Public Exposure to Electric and Magnetic Fields as Specified in Table 7 and Table 8

Frequency	E-field strength (V/m rms)		H-field strength (A/m rms)		Equivalent plane wave power flux density S_{eq} (W/m^2)	
	Time Average from Table 7	Instantaneous from Table 8	Time Average from Table 7	Instantaneous from Table 8	Time Average from Table 7	Instantaneous from Table 8
3 kHz	–	86.8	–	4.86	–	–
10 kHz	–	86.8	–	4.86	–	–
65 kHz	–	86.8	–	4.86	–	–
70 kHz	–	86.8	–	4.86	–	–
80 kHz	–	86.8	–	4.86	–	–
90 kHz	–	86.8	–	4.86	–	–
100 kHz	86.8	86.8	4.86	4.86	–	–
150 kHz	86.8	118	4.86	4.86	–	–
200 kHz	86.8	146	3.65	4.62	–	–
250 kHz	86.8	173	2.92	4.44	–	–
300 kHz	86.8	198	2.43	4.30	–	–
400 kHz	86.8	245	1.82	4.08	–	–
500 kHz	86.8	290	1.46	3.93	–	–
600 kHz	86.8	333	1.22	3.80	–	–
700 kHz	86.8	373	1.04	3.70	–	–
800 kHz	86.8	413	0.911	3.61	–	–
900 kHz	86.8	451	0.810	3.54	–	–
1 MHz	86.8	488	0.729	3.47	–	–
1.5 MHz	70.9	540	0.486	3.23	–	–
2 MHz	61.4	580	0.365	3.07	–	–
3 MHz	50.1	642	0.243	2.85	–	–
4 MHz	43.4	690	0.182	2.71	–	–
5 MHz	38.8	730	0.146	2.61	–	–
6 MHz	35.4	764	0.122	2.52	–	–
7 MHz	32.8	794	0.104	2.45	–	–
8 MHz	30.7	821	0.0911	2.40	–	–
9 MHz	28.9	845	0.0810	2.35	–	–
10 MHz	27.4	868	0.0729	2.30	2.00	2000
100 MHz	27.4	868	0.0729	2.30	2.00	2000
400 MHz	27.4	868	0.0729	2.30	2.00	2000
500 MHz	30.6	970	0.0814	2.57	2.50	2500
600 MHz	33.6	1063	0.0892	2.82	3.00	3000
700 MHz	36.2	1148	0.0963	3.04	3.50	3500
800 MHz	38.7	1228	0.103	3.25	4.00	4000
900 MHz	41.1	1302	0.109	3.45	4.50	4500
1 GHz	43.3	1372	0.115	3.64	5.00	5000
1.5 GHz	53.1	1681	0.141	4.45	7.50	7500
1.8 GHz	58.1	1841	0.154	4.88	9.00	9000
2 GHz	61.4	1941	0.163	5.15	10.0	10000
10 GHz	61.4	1941	0.163	5.15	10.0	10000
100 GHz	61.4	1941	0.163	5.15	10.0	10000
300 GHz	61.4	1941	0.163	5.15	10.0	10000

NOTE: General public E and H reference levels are given in plane wave ratio at frequencies greater than or equal to 10 MHz. However, equivalent plane wave power flux density is not an appropriate metric if 'far-field' exposure conditions do not apply. Survey meters may be calibrated in terms of W/m^2, but both E and H will generally require independent measurement and evaluation if measured in the near-field (refer Schedule 4). Appropriate conversion factors are given in Table A2 of Annex 1.

Schedule 4

Equivalent Power Flux Density

As specified in Table 7 and Table 8, for occupational exposure at frequencies above 1 MHz and for general public exposure at frequencies above 10 MHz, the magnitude of the reference levels for both electric and magnetic field strength are defined in the ratio E/H ≈ 377 ohms and this is equivalent to the ratio for a far-field plane wave exposure (refer Annex 1 for quantities and unit conversion factors). In particular, for general public exposure to frequencies below 10 MHz, or 1 MHz in the case of occupational exposure, the E and H reference levels do not follow such relationship and both E and H will require separate evaluation. Furthermore, under near-field exposure conditions, both E and H would usually require independent measurement and evaluation regardless of the relative magnitude of specific reference levels.

The sensors used in survey meters usually respond only to E or H fields (but not both) and are often calibrated in terms of W/m² and figures 3 and 4 are only provided for guidance with conversion.

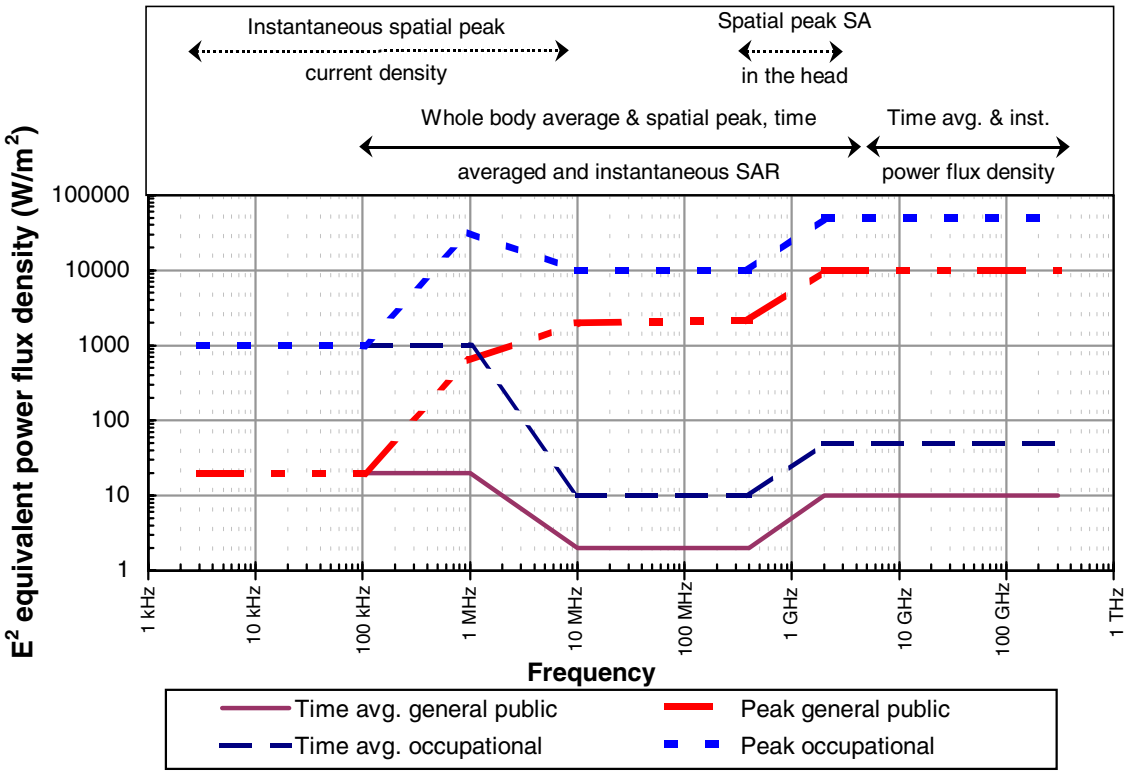


Figure 3 Equivalent power flux density for peak and time averaged exposure to electric fields (refer Tables 7 and 8 and look-up tables in Schedules 2 and 3).

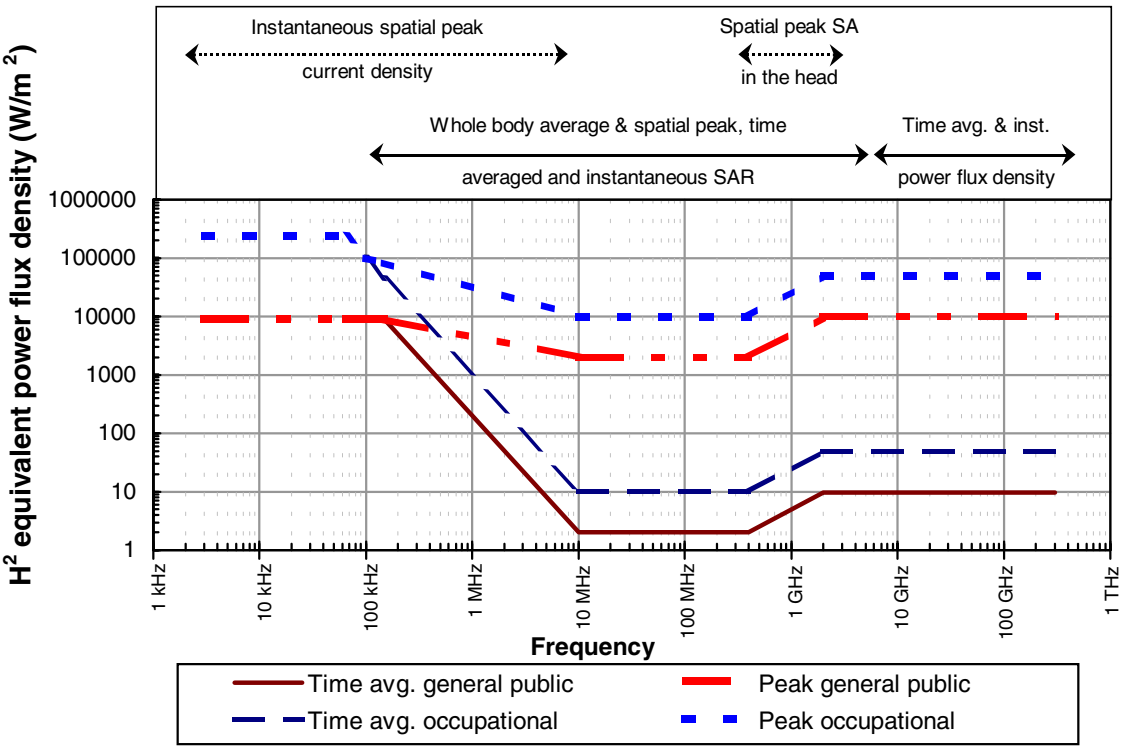


Figure 4 Equivalent power flux density for peak and time averaged exposure to magnetic fields (refer Tables 7 and 8 and look-up tables in Schedules 2 and 3).

Schedule 5

Compliance of Mobile or Portable Transmitting Equipment (100 kHz To 2500 MHz)

S5.1 General

Mobile or portable transmitting equipment may be designed to be used close to the body. This can result in illumination of a small portion of the user's body and produces fields with a highly non-uniform spatial distribution. In such circumstances it is practicable to determine compliance from a consideration of equipment parameters and conditions of use. Table S1 summarises the detailed requirements of this Schedule. These provisions apply only to transmitting equipment that emits RF fields at frequencies between 100 kHz and 2500 MHz.

S5.2 Equipment Intended for Use by Aware Users

S5.2.1 Application

Sub-section S5.2 provides a means, based on equipment and usage parameters, to readily determine compliance with the spatial peak SAR restrictions of Table 2 for occupational exposure. This sub-section applies to equipment operated by aware users.

S5.2.2 Equipment with mean power output not exceeding 100 mW

The evaluation of mobile or portable transmitting equipment for compliance with this Standard is not required where the nominal mean power output delivered to the antenna does not exceed 100mW.

S5.2.3 Equipment with mean power output exceeding 100 mW

The evaluation of mobile or portable transmitting equipment for compliance with this Standard is not required where:

(a) it operates on a push-to-talk basis;

(b) it is used by an aware user;

(c) it is operated with a transmit duty factor of 50% or less averaged over a six minute period;

(d) it does not exceed the power levels of Table S2; and

(e) normal operation entails the antenna or other radiating structure being separated from the user's body by not less than 2.5 cm.

Where the above provisions are not satisfied, testing or mathematical modelling to demonstrate compliance with the spatial peak SAR restrictions as specified for the Occupational category in Table 2 of this Standard must be undertaken. Such measurements or calculations should be based on normal use spatial relationships between the equipment and user.

The compliance of transmitting equipment may be assessed, via the derived reference levels for the occupational category of Tables 7 and 8, by direct measurement or evaluation in accordance with the recommendations of AS/NZS 2772.2 or other appropriate guidelines where the power output exceeds the levels of Table S2 and normal operation entails the antenna or other radiating structure being separated from the user's body by not less than 20 cm.

Where operation of the equipment under unusual or inappropriate conditions is liable to exceed the spatial peak SAR restrictions of Table 2 for occupational exposure, instructional material must be provided to caution the user against such usage. This should include any requirements regarding minimum separations.

S5.3 Equipment Intended for Use by the General Public

S5.3.1 Application

Sub-section S5.3 provides a means, based on equipment and usage parameters, to readily determine compliance with the spatial peak SAR restrictions of Table 2 for general public exposure of certain portable or mobile equipment. This sub-section has application to equipment intended for operation by general public users.

S5.3.2 Equipment with mean output power not exceeding 20 mW

The evaluation of mobile or portable transmitting equipment for compliance with this Standard is not required where the nominal mean power output delivered to the antenna does not exceed 20 mW.

S5.3.3 Equipment with mean output power exceeding 20 mW

The evaluation of mobile or portable transmitting equipment for compliance with this Standard is not required where:

(a) it operates on a push-to-talk basis;

(b) it is operated with a transmit duty factor of 50% or less averaged over a six minute period;

(c) it does not exceed one fifth (20%) of the power levels of Table S2; and

(d) normal operation entails the antenna or other radiating structure being separated from the user's body by not less than 2.5 cm.

The evaluation of mobile or portable transmitting equipment for compliance with this Standard is not required where the output power delivered to the antenna does not exceed the levels of Table S2 and normal operation entails the antenna or other radiating structure being separated from the user's body by not less than 20 cm.

Where the above provisions are not satisfied, testing or mathematical modelling to demonstrate compliance with the spatial peak SAR restrictions specified for the general public users category in Table 2 of this Standard must be undertaken. Such measurements or calculations should be based on normal use spatial relationships between the equipment and user.

The compliance of transmitting equipment may be assessed, via the reference levels specified for the general public users category in Tables 7 and 8 of this Standard, by direct measurement or evaluation in accordance with the recommendations of AS/NZS 2772.2 or other appropriate guidelines where the power output exceeds the levels of Table S2; and normal operation entails the antenna or other radiating structure being separated from the user's body by not less than 20 cm.

Where operation of the equipment under unusual or inappropriate conditions is liable to exceed the spatial peak SAR restrictions of Table 2 for general public exposure, instructional material must be provided to caution the user against such usage. This should include any requirements regarding minimum separations.

TABLE S1

SUMMARY OF COMPLIANCE PROVISIONS FOR MOBILE OR PORTABLE TRANSMITTING EQUIPMENT

Equipment parameters	**Test exemption**	**Spatial peak SAR** [Table 2 Occupational]	**Spatial peak SAR** [Table 2 General Public]	**Field measurement** [Tables 7 & 8 Occupational or evaluation using S5.2.3]	**Field measurement** [Tables 7 & 8 General Public or evaluation using S5.3.3]
Aware user exposure					
Mean power < 100 mW	✓				
Push-to-talk & mean power < Table S2 & duty factor < 50 % & separation > 2.5 cm	✓				
Mean power > Table S2 & separation > 20 cm				✓	
Otherwise		✓			
General public exposure					
Mean power < 20 mW	✓				
Push-to-talk & mean power < 1/5 of Table S2 & duty factor < 50 % & separation > 2.5 cm	✓				
Mean power < Table S2 & separation > 20 cm	✓				
Mean power > Table S2 & separation > 20 cm					✓
Otherwise			✓		

NOTE: Fixed or vehicle mounted transmitting equipment should be installed in accordance with AS/NZS 4346.

TABLE S2

THRESHOLD LEVELS FOR TESTING

Operating frequency range			Nominal mean output power (W)
100 kHz	to	450 MHz	7
450 MHz	to	2500 MHz	3150 / f

NOTES:

1 For the purpose of this Schedule, mean power is as defined in ITU Radio Regulations as the average power over an interval of time which is long compared with the lowest modulating frequency (except for pulse-modulated or intermittent transmissions where mean power is to be taken as peak-envelope-power (PEP) multiplied by duty factor. For duty factors of less than 5 %, mean power is to be taken as 5 % of PEP).

2 ***f* is the frequency in MHz**.

Glossary

Absorption

In radio wave propagation, attenuation of a radio wave due to dissipation of its energy, i.e., conversion of its energy into another form, such as heat.

Athermal (low level) effect

Any effect that is not related to heating that results from the interaction of RF fields on a biological system.

Averaging time
The interval of time over which quantities, power terms (SAR, SA, S) or root mean square values (E, H, J, I), are averaged to assess exposure. Practical measurement considerations of averaging times are discussed in Section 2 of the Standard.

Aware user

A person who is appropriately trained to use two-way radios and other portable wireless devices (see Schedule 5, clause S5.2) which expose the user to levels likely to exceed the basic restrictions for general public exposure. Appropriate training includes awareness of the potential for exposure and measures that can be taken to control that exposure. Persons in the aware user group may include, but are not limited to, the following categories:

(a) Emergency service personnel.

(b) Amateur radio operators.

(c) Voluntary civil defence personnel.

Also refer Glossary definitions for: Controlled area; General public exposure; Occupational exposure; RF worker.

Basic restrictions

The mandatory limiting values of exposure expressed in terms of selected quantities that closely match all known biophysical interaction mechanisms that may lead to health effects.

Conductance

The reciprocal of resistance. Expressed in siemens (S).

Conductivity, electrical

The scalar or vector quantity which, when multiplied by the electric field strength, yields the conduction current density; it is the reciprocal of resistivity. Expressed in siemens per metre (S/m).

Continuous wave (CW)

An unmodulated electromagnetic wave.

Controlled area

A controlled area is an area or place in which exposure to RF fields may reasonably be expected to exceed general public limits, and with the following characteristics:

(a) The area must be under the supervision of a competent person who must ensure that exposures cannot exceed occupational levels;

(b) The area may only be entered by persons who are made aware that they are doing so, and of the need for RF safety;

(c) There must be documentation or signage to clearly indicate:

  (i) areas above occupational limits;

  (ii) areas above general public limits.

Also refer Glossary definitions for: Aware user, General public exposure; Occupational exposure; RF worker.

Current density

A vector of which the integral over a given surface is equal to the current flowing through the surface; the mean density in a linear conductor is equal to the current divided by the cross-sectional area of the conductor. Expressed in ampere per square metre (A/m^2).

Dosimetry

Measurement, or determination by calculation, of internal electric field strength or induced current density or specific absorption (SA), or specific absorption rate (SAR), in humans or animals exposed to electromagnetic fields.

Duty factor

The ratio of pulse duration to the pulse period of a periodic pulse train. For example, a CW transmission corresponds to a duty factor of 1.0.

Electric field strength

The rms magnitude of the electric field vector, *(*E) expressed in volts per metre (V/m).

Electromagnetic energy

The energy stored in an electromagnetic field. Expressed in joule (J).

EMF

Electromagnetic fields.

Equivalent power flux density

The magnitude of the power flux density that corresponds with an electromagnetic wave propagating as a plane wave through free space (refer Schedule 4).

Exposure

That which occurs whenever a person is subject to the influence of a RF field or contact current.

Frequency

The number of sinusoidal cycles completed by electromagnetic waves in 1 second; usually expressed in hertz (Hz).

General public exposure

All exposure to RF fields received by members of the general public. This definition excludes occupational exposure, exposure of aware users, and medical exposure. It is recognised that some persons may need to transit controlled areas (as defined), and this is permitted under adequate supervision.

Also refer Glossary definitions for: Aware user, Controlled area; Medical exposure; Occupational exposure; RF worker.

Hertz (Hz)

The unit for expressing frequency, (*f*). One hertz equals one cycle per second. 1 kHz = 1000 Hz, 1 MHz = 1000 kHz, 1 GHz = 1000 MHz.

Instantaneous

Adjective used to describe particular parameters that must be measured or evaluated over a very short time interval (typically 100 microseconds or less).

Magnetic field strength

The rms magnitude of the magnetic field vector *(*H) expressed in amperes per metre (A/m).

Magnetic flux density

A vector field quantity, B, that results in a force that acts on a moving charge or charges, and is expressed in tesla (T).

Medical exposure

Exposure of a person to RF fields received as a patient undergoing medical diagnosis or recognised medical treatment, or as a volunteer in medical research.

Microwave

Electromagnetic radiation of sufficiently short wavelength for which practical use can be propagated through waveguide and associated cavity techniques in its transmission and reception. *Note:* The term is taken to signify radiations or fields having a frequency range of 300 MHz – 300 GHz.

Mobile or portable transmitting equipment

A telecommunications transmitter that is designed to be used on land, on water or in the air, either while in motion, or during halts at unspecified points.

NOTE: There is no clear distinction in the use of the words 'mobile' or 'portable'. However the word 'portable' often refers to a transmitter used within twenty centimetres of the body (e.g. mobile phone or army man pack) while 'mobile' often refers to transmitter used at distances greater than twenty centimetres from the body (e.g. vehicle mounted equipment).

Modulated field

A RF field, the amplitude, phase or frequency of which varies with time.

Partial-body exposure

Exposure which occurs when RF fields are substantially non-uniform over the body. Fields that are non-uniform over volumes comparable to the human body may occur due to highly directional sources, standing-waves, re-radiating sources or in the near-field.

Occupational exposure

For the purposes of this standard, occupational exposure is defined as exposure of a RF worker (as defined) to RF fields when on duty.

Also refer Glossary definitions for: Aware user, Controlled area; General public exposure; RF worker.

Permittivity

A constant defining the influence of an isotropic medium on the forces of attraction or repulsion between electrified bodies, and expressed in farad per metre (F/m); *relative permittivity* is the permittivity of a material or medium divided by the permittivity of vacuum.

Plane wave

An electromagnetic wave in which the electric and magnetic field vectors lie in a plane perpendicular to the direction of wave propagation, and the magnitude of the magnetic field strength multiplied by the impedance of space is equal to the magnitude of the electric field strength (refer Schedule 4).

Point contact

Contact of a small area of the body (such as a fingertip) with an energised or passively charged conductive surface.

Power flux density

The rate of flow of RF energy through a unit area normal to the direction of wave propagation; expressed in watt per square metre (W/m^2).

Public exposure

Refer Glossary definition: General public exposure.

Radiofrequency (RF)

Electromagnetic energy with frequencies in the range 3 kHz to 300 GHz.

Reasonable accommodation/adjustment

The variation of usual employment practices or the work environment, when necessary, possible and reasonable, to enable an employee to continue working in safety. Examples of such employees could include those who are pregnant and those with implants.

Reference levels

Practical or 'surrogate' parameters that may be used for determining compliance with the basic restrictions.

RF field

A physical field, which specifies the electric and magnetic states of a medium or free space, quantified by vectors representing the electric field strength and the magnetic field strength.

The field is comprised of three regions, as follows:

(a) *Reactive near-field*—that region of the field immediately surrounding the antenna wherein the reactive field predominates. The commonly accepted distance to the reactive near-field boundary is $\lambda/2\pi$ m, λ being the wavelength in metres.

(b) *Radiating near-field*—that region of the field, which extends between the reactive near-field region and the far-field region, wherein radiated fields predominate and the angular field distribution is dependent upon distance from the antenna.

(c) *Far-field*—that region of the field of the antenna where the angular field distribution is essentially independent of the distance from the antenna. If the antenna has a maximum overall dimension D, the far-field region is commonly taken to exist at distances greater than $2D^2/\lambda$ or 0.5λ, whichever is the greater, from the antenna.

NOTE: The formulae given above are generally conservative and are based on considerations of antenna pattern formation, i.e. the angular distribution of the radiated energy is essentially independent of the distance from the antenna in the far-field.

RF worker

A person who may be exposed to RF fields under controlled conditions, in the course of and intrinsic to the nature of their work. Such persons are subject to the requirements of Section 5.1.

Also refer Glossary definitions for: Aware user, Controlled area; General public exposure; Occupational exposure.

Root mean square (rms)

The square root of the mean of the square of a time variant function, F(t), over a specified time period from t_1 to t_2. It is derived by first squaring the function and then determining the mean value of the squares obtained, and taking the square root of that mean value, i.e.

$$F_{rms} = \sqrt{\frac{1}{t_2 - t_1}\int_{t_1}^{t_2}[F(t)]^2\,dt}$$

Spatial Peak

Term used to describe the highest level of a particular quantity averaged over a small mass or area in the human body.

Specific absorption (SA)

The energy absorbed per unit mass of biological tissue during a RF pulse. It is expressed in joule per kilogram (J/kg). SA is the time integral of the specific RF energy absorption rate during a pulse.

Specific absorption rate (SAR)

The rate at which RF energy is absorbed in body tissues, in watts per kilogram (W/kg).

Unperturbed field

The electric or magnetic field, generated by a source, that has no reflected or re-radiated field components.

Wavelength

The distance between two successive points of a periodic wave in the direction of propagation, at which the oscillation has the same phase.

Annex 1

Quantities and Units

Electromagnetic fields are quantified in terms of electric field strength **E**, expressed in volt per metre (V/m) and magnetic field strength **H** expressed as amperes per metre (A/m). Electric fields are associated only with the presence of electric charge, while magnetic fields result from the physical movement of electric charge (electric current). An electric field exerts forces on an electric charge and similarly, magnetic fields can exert physical forces on electric charges, but only when such charges are in motion. Electric and magnetic fields have both magnitude and direction (i.e., they are vectors). A magnetic field can also be specified as magnetic flux density, **B**, expressed in tesla (T). The two quantities, **B** and **H**, are related by the expression:

$$\mathbf{B} = \mu\mathbf{H} \tag{1}$$

where μ is the constant of proportionality (the magnetic permeability); in a vacuum and in air, as well as in non-magnetic (including biological) materials, μ has the value $4\pi \times 10^{-7}$ when expressed in henry per metre. Thus, in describing a magnetic field for protection purposes, only one of the quantities **B** or **H** needs to be specified.

In the far-field region, the plane wave model is a good approximation of the electromagnetic field propagation. The characteristics of a plane wave are:

- the wave fronts have a planar geometry;
- the **E** and **H** vectors and the direction of propagation are mutually perpendicular;
- the phase of the **E** and **H** fields is the same, and the quotient of the amplitude of **E**/**H** is constant throughout space. In free space, the ratio of their amplitudes $|\mathbf{E}|/|\mathbf{H}| \approx 377$ ohm, which is the characteristic impedance of free space; and
- power flux density, **S,** i.e., the power per unit area normal to the direction of propagation, is related to the electric and magnetic fields by the expressions:

$$\mathbf{S} = \mathbf{E} \times \mathbf{H} \tag{2a}$$

$$|\mathbf{S}| = \frac{|\mathbf{E}|^2}{377} = 377\,|\mathbf{H}|^2 \tag{2b}$$

The situation in the near-field region is rather more complicated because the maxima and minima of **E** and **H** fields do not occur at the same points along the direction of propagation as they do in the far-field. In the near-field, the electromagnetic field structure may be highly inhomogeneous, and there may be substantial variations from the plane wave impedance of 377 ohms; that is, there may be almost pure **E** fields in some regions and almost pure **H** fields in others. Exposures in the near field are more difficult to specify, because both **E** and **H** fields must be measured and because the field patterns are more complicated; in this situation, power flux density is no longer an appropriate quantity to use in expressing exposure restrictions (as in the far-field).

Exposure to time-varying EMF results in internal body currents and energy absorption in tissues that depend on the coupling mechanisms and the frequency involved. The internal electric field and current density are related by Ohm's Law:

$$\mathbf{J} = \sigma\mathbf{E} \quad (3)$$

where σ is the electrical conductivity of the medium. The dosimetric quantities used in this standard, taking into account different frequency ranges and waveforms, are as follows:

- current density, **J**, in the frequency range 3 kHz - 10 MHz;
- current, **I**, in the frequency range 3kHz - 110 MHz;
- specific absorption rate, SAR, in the frequency range 100 kHz 10 GHz;
- specific absorption, SA, for pulsed fields in the frequency range 300 MHz - 6 GHz;
- power flux density, **S,** in the frequency range 6 GHz - 300 GHz.

A general summary of EMF and dosimetric quantities and units used in this standard is provided in Table A1.

TABLE A1

ELECTRIC, MAGNETIC, ELECTROMAGNETIC, AND DOSIMETRIC QUANTITIES & CORRESPONDING SI UNITS

Quantity	Symbol	Unit
Conductivity	σ	Siemens per metre (S/ m)
Current	**I**	Ampere (A)
Current Density	**J**	Ampere per square metre (A/m^2)
Frequency	f	Hertz (Hz)
Electric field strength	**E**	Volt per metre (V /m)
Magnetic field strength	**H**	Ampere per metre (A/ m)
Magnetic flux density	**B**	Tesla (T)
Magnetic permeability	μ	Henry per metre (H /m)
Permittivity	ε	Farad per metre (F/m)
Power flux density	**S**	Watt per square metre (W/m^2)
Specific absorption	SA	Joule per kilogram (J /kg)
Specific absorption rate	SAR	Watt per kilogram (W/ kg)

TABLE A2

UNIT CONVERSION TABLE

Given quantity [unit]	Desired quantity [unit]				
	S [W/m²]	**S [mW/cm²]**	**S [μW/cm²]**	**E [V/m]**	**H [A/m]**
S [W/m²]	$1 \times S$	$0.1 \times S$	$100 \times S$	$\sqrt{(S_{eq} \times 377)}$	$\sqrt{(S_{eq} / 377)}$
S [mW/cm²]	$10 \times S$	$1 \times S$	$1000 \times S$	$\sqrt{(S_{eq} \times 3770)}$	$\sqrt{(S_{eq} / 37.7)}$
S [μW/cm²]	$0.01 \times S$	$0.001 \times S$	$1 \times S$	$\sqrt{(S_{eq} \times 3.77)}$	$\sqrt{(S_{eq} / 37700)}$
E [V/m]	$E_{eq}^2 / 377$	$E_{eq}^2 / 3770$	$E_{eq}^2 / 3.77$	$1 \times E$	$E_{eq} / 377$
H [A/m]	$H_{eq}^2 \times 377$	$H_{eq}^2 \times 37.7$	$H_{eq}^2 \times 37700$	$H_{eq} \times 377$	$1 \times H$

NOTES:

1 Unit conversion is carried out by selecting the relevant quantity to be converted from the given quantity column and applying the appropriate formula in the table.

2 The factors given in Table A2 are based on a free space impedance of 377 ohm and are only appropriate for far-field "plane wave" conditions.

3 Quantities with the subscript 'eq' indicate the equivalent plane wave relationship.

Annex 2

Coupling Mechanisms between RF Fields and the Body

There are three established basic coupling mechanisms through which time-varying electric and magnetic fields interact directly with living matter:

- coupling to low-frequency electric fields;
- coupling to low-frequency magnetic fields; and
- absorption of energy from electromagnetic fields.

Coupling to low-frequency RF electric fields

The interaction of time-varying electric fields with the human body results in the flow of electric charges (electric current), the polarisation of bound charge (formation of electric dipoles), and the reorientation of electric dipoles already present in tissue. The relative magnitudes of these different effects depend on the electrical properties of the body - that is, electrical conductivity (governing the flow of electric current) and permittivity (governing the magnitude of polarisation effects). Electrical conductivity and permittivity vary with the type of body tissue and also depend on the frequency of the applied field. Electric fields external to the body induce a surface charge on the body; this results in induced currents in the body, the distribution of which depends on exposure conditions, on the size and shape of the body, and on the body's position in the field.

Coupling to low-frequency RF magnetic fields

The physical interaction of time-varying magnetic fields with the human body results in induced electric fields and circulating electric currents. The magnitudes of the induced field and the current density are proportional to the radius of the loop, the electrical conductivity of the tissue, and the rate of change and magnitude of the magnetic flux density. For a given magnitude and frequency of magnetic field, the strongest electric fields are induced where the loop dimensions are greatest. The exact path and magnitude of the resulting current induced in any part of the body will depend on the electrical conductivity of the tissue.

The body is not electrically homogeneous; however, induced current densities can be calculated using anatomically and electrically realistic models of the body and computational methods, which have a high degree of anatomical resolution.

Absorption of energy from RF fields

Exposure to low-frequency electric and magnetic fields normally results in negligible energy absorption and no measurable temperature rise in the body. However, exposure to electromagnetic fields at frequencies above about 100 kHz can lead to significant absorption of energy and temperature increases. In general, exposure to a uniform (plane wave) electromagnetic field results in a highly non-uniform deposition and distribution of energy within the body, which must be assessed by dosimetric measurement and calculation.

As regards absorption of energy by the human body, electromagnetic fields can be divided into four ranges (Dumey 1980):

- frequencies from about 100 kHz to less than about 20 MHz, at which absorption in the torso decreases rapidly with decreasing frequency, and significant absorption may occur in the neck and legs;
- frequencies in the range from about 20 MHz to 300 MHz, at which relatively high absorption can occur in the whole body, and to even higher values if partial body (e.g., head) resonances are considered;
- frequencies in the range from about 300 MHz to several GHz, at which significant local, non-uniform absorption occurs; and
- frequencies above about 10 GHz, at which energy absorption occurs primarily at the body surface.

In tissue, SAR is proportional to the square of the internal electric field strength. Average SAR and SAR distribution can be computed or estimated from laboratory measurements. Values of SAR depend on the following factors:

- the incident field parameters, i.e., the frequency, intensity, polarisation, and source-object configuration (near- or far-field);
- the characteristics of the exposed body, i.e., its size and internal and external geometry, and the dielectric properties of the various tissues;
- ground effects and reflector effects of other objects in the field near the exposed body.

When the long axis of the human body is parallel to the electric field vector, and under plane wave exposure conditions (i.e., far-field exposure), whole-body SAR reaches maximal values. The amount of energy absorbed depends on a number of factors, including the size of the exposed body. 'Standard Reference Man' (ICRP 1994), if not grounded, has a resonant absorption frequency close to 70 MHz. For taller individuals the resonant absorption frequency is somewhat lower, and for shorter adults, children, babies, and seated individuals it may exceed 100 MHz. The values of electric field reference levels are based on the frequency-dependence of human absorption; in grounded individuals, resonant frequencies are lower by a factor of about 2 (WHO 1993).

For some devices that operate at frequencies above 10 MHz (e.g., dielectric heaters, mobile telephones), human exposure can occur under near-field conditions. The frequency-dependence of energy absorption under these conditions is very different from that described for far-field conditions. Magnetic fields may dominate for certain devices, such as mobile telephones, under certain exposure conditions.

The usefulness of numerical modelling calculations, as well as measurements of induced body current and tissue field strength, for assessment of near-field exposures has been demonstrated for mobile telephones, walkie-talkies, broadcast towers, shipboard communication sources, and dielectric heaters (Kuster & Balzano 1992; Dimbylow & Mann 1994; Jokela, Puranen & Gandhi 1994; Gandhi 1995; Tofani et al. 1995). The importance of these studies lies in their having shown that near-field exposure can result in high local SAR (e.g., in the head, wrists, ankles) and that whole-body and local SAR are strongly dependent on the separation distance between the high-frequency source and the body. Finally, SAR data obtained by measurement are consistent with data obtained from numerical modelling calculations. Whole-body average SAR and local SAR are convenient quantities for comparing effects observed under various exposure conditions. A detailed discussion of SAR can be found elsewhere (WHO 1993).

At frequencies greater than about 10 GHz, the depth of penetration of the field into tissues is small, and SAR is not a good measure for assessing absorbed energy; the incident power flux density of the field (in W/m^2) is a more appropriate dosimetric quantity.

Indirect coupling mechanisms

There are two indirect coupling mechanisms:

- contact currents that result when the human body comes into contact with an object at a different electric potential (i.e., when either the body or the object is charged by an EMF); and
- coupling of EMF to medical devices worn by, or implanted in, an individual (not considered in this document).

The charging of a conducting object by EMF causes electric currents to pass through the human body in contact with that object (Tenforde & Kaune 1987; WHO 1993). The magnitude and spatial distribution of such currents depend on frequency, the size of the object, the size of the person, and the area of contact; transient discharges (sparks) can occur when an individual and a conducting object exposed to a strong field come into close proximity.

References

Dimbylow, P. J. & Mann, J.M. 1994, 'SAR calculations in an anatomically realistic model of the head for mobile communication transceivers at 900 MHz and 1.8 GHz', *Physics in Medicine and Biology*, vol. 39, pp. 1527-1553.

Dumey, C. H. 1980. 'Electromagnetic dosimetry for models of humans and animals: a review of theoretical and numerical techniques', *Proceedings of the IEEE*, vol. 68, pp. 33-40.

Gandhi, O. 1995, 'Some numerical methods for dosimetry: extremely low frequencies to microwave frequencies', *Radio Science*, vol. 30, pp. 161-177.

ICRP 1994, 'Human respiratory tract model for radiological protection', *Annals of the ICRP*, Publication 66, vol. 24, pp. 1-3.

Jokela, K., Puranen, L. & Gandhi, O. P. 1994, 'Radio Frequency Currents Induced in the Human Body for Medium-Frequency/High-Frequency Broadcast Antennas', *Health Physics*, vol. 66, no. 3, pp. 237-244.

Kuster, N. & Balzano, Q. 1992, 'Energy absorption mechanism by biological bodies in the near field of dipole antennas above 300 MHz', *IEEE Transactions on Vehicular Technology*, vol. 41, no. 1, pp. 17-23.

Tenforde, T. S. & Kaune, W. T. 1987, 'Interaction of extremely low frequency electric and magnetic fields with humans', *Health Physics*, vol. 53, pp. 585-606.

Tofani, S., Anglesio, L, Ossola, P. & d'Amore, G. 1995 'Spectral Analysis of Magnetic Fields from Domestic Appliances and Corresponding Induced Current Densities in an Anatomically Based Model of the Human Head', *Bioelectromagnetics*, vol. 16, no. 6, pp. 356-364.

World Health Organization (WHO) 1993 *Electromagnetic fields (300 Hz to 300 GHz)*, Environmental Health Criteria No. 137, United Nations Environment Programme/International Radiation Protection Association/World Health Organization, Geneva Switzerland.

Annex 3

Epidemiological Studies of Exposure to RF Fields and Human Health

Summary

The epidemiological evidence does not give clear or consistent results which indicate a causal role of RF field exposures in connection with any human disease. On the other hand, the results cannot establish the absence of any hazard, other than to indicate that for some situations any undetected health effects must be small (Elwood 1999).

Cancer is the disease that has been studied most extensively, and although there are many individual associations seen, there is little overall consistency in the results. None of these studies give good information on individual levels of exposure. The studies of general populations living near radio or television transmitters relate to radiofrequency exposures likely to be well below currently accepted standards. The studies of military personnel and occupational groups may include some exposures beyond general population standards.

Of the individual studies, the general population study in the UK (Dolk et al. 1997a) is sufficiently strong to reasonably exclude a geographical pattern with an excess of human cancers in subjects living close to large television and radio transmitters, although there is still a possible question in regard to adult leukaemia. The Motorola employees' study (Morgan et al. 2000) is sufficiently powerful to reasonably exclude a substantial excess of leukaemia or lymphoma in about ten years from radiofrequency exposure in these workers. This time interval is not long enough to exclude an incidence effect, but it does provide substantial evidence against a short-term promotion effect, such as has been suggested by some animal experiments. The large population based study of mobile phone subscribers in Denmark (Johansen et al. 2001a) also gives substantial evidence against there being any short term increases in cancer with typical levels of phone use experienced by residential subscribers. None of these large studies can provide good information on the intensities of exposure experienced by the people studied.

There are now three case control studies published on brain cancer in relationship to personal use of mobile phones, which show no consistent evidence of any increased risk (Hardell et al. 1999; Inskip et al. 2001; Muscat et al. 2000). One recent small study showed an increased risk of ocular melanoma, which requires validation (Stang et al. 2001).

The other epidemiological studies of radiofrequency exposures and human disease outcomes show little consistency. The results for congenital malformations and spontaneous abortions are inconsistent. The results from the Swiss studies (Altpeter et al. 1995) on self-reported sleep disturbances are difficult to interpret because of the subjective nature of the outcomes assessed and the potential for recall bias. Of the human studies of exposures under experimental conditions, one study (Braune et al. 1998) showed an increase in blood pressure after an exposure similar to mobile phone use, and this study needs replication.

Other studies are in progress, including those in the World Health Organization International EMF project: www.who.int/peh-emf.

Implications for Exposure Standards

Epidemiological studies primarily relate to the question of whether there is or is not an increased risk of disease in human populations exposed to the suspect agent. The studies include some which assess likely low levels of exposure, well within current standards, as well as some which may be assessing irregular higher exposure levels; in none of the studies is detailed exposure information available. Therefore, the epidemiological work is not directly helpful in defining a particular level of radiofrequency exposure which could be hazardous. Equally, the epidemiological evidence does not support an argument for any particular changes in currently accepted exposure standards.

The epidemiological studies reviewed here do not suggest that currently accepted exposure standards, such as that of the International Commission on Non-Ionizing Radiation Protection (ICNIRP), need to be revised downwards. The overall conclusion from the literature is that no detrimental health effects have been observed consistently in studies which are assessing exposure levels which are likely to be within the current standards or which may have occasionally been beyond those standards, for example in the occupational studies. As is expected in any area of work where there are numbers of studies, some making multiple observations, there are some positive associations reported: but overall these are more likely to be due to chance variation, biases in the observations made in the study, or the effects of other related factors, than due to a causal association with radiofrequency exposures.

The negative experimental evidence on markers of serious effects, for example in vivo and in vitro indicators of carcinogenesis, and the absence of well established biological effects of any sort, argue strongly against there being any health effects at very low levels of exposure. This would apply to the levels of exposure characteristic of general population exposures from mobile phone base transmitter sites, where typically exposures are below one percent of the current ICNIRP standard.

The exposures to the head in users of mobile phones are considerably higher, and although experimental evidence shows no evidence of carcinogenic mechanisms or clearly abnormal cellular effects, recent research raises the possibility of biological or psychological effects. These experimental results are unconfirmed and inconsistent, and where effects have been shown their importance in terms of health is unclear; however the possibility of a detrimental effect is difficult to dismiss completely. Epidemiological studies concerning mobile phone users are proceeding, particularly in regard to tumours of the central nervous system.

Principles of epidemiology

Epidemiology is '*the study of the distribution and determinants of disease in human populations*' (MacMahon & Pugh 1970, p.1). It is the science which studies the causes of disease in human free-living populations, in contrast to studying causal mechanisms in experimental animals or cell systems.

Very occasionally, where a particular causal agent is the only (or almost the only) cause of a specific disease and has a very clear and strong effect, a causal relationship can be established on the basis of one, or only a few, well-conducted studies; examples include occupational studies of asbestos exposure, and the studies of those affected by radiation from the atomic bombs in Japan in 1945. Much more commonly, however, the causes of a disease are established by the cumulative evidence provided by a large number of different studies, rather than

by one particular study. If an association is seen between a possible causal factor and a disease (for example, between exposure to radiofrequencies and the development of cancer) a careful evaluation of the extent and quality of the studies showing that association is necessary, before concluding that there is likely to be a cause and effect relationship, or whether the associations seen are more likely to be due to other factors.

Studies in human populations, unlike experimental studies in a laboratory, are limited to what can be done ethically and logistically in free-living human subjects. Thus the exactitude of the data collected, and the ability to isolate the effects of one factor from those of other factors, are usually less controllable than they are in a laboratory situation. In contrast, epidemiological studies, unlike laboratory studies, are directly relevant to causation of disease in human individuals and populations, and can assess 'real life' exposures, which are often more complex than those used in the laboratory.

As with any science, the results of epidemiological studies, whether they show an association or not, will often be affected by limitations of the study design or analysis. The results may be influenced by errors or bias in the data, the influence of other relevant factors, or by chance variation. These all have to be assessed carefully before the study can be interpreted as showing a cause and effect relationship, or giving good evidence against such a relationship. There are well-established principles which assist in interpreting epidemiological data.

There are several major types of study. The strongest evidence to assess a cause and effect relationship comes from an *experimental study*, in which subjects deliberately exposed to a certain factor can be compared to similar subjects not exposed (for example, in trials of immunisation, consenting subjects can be randomly allocated to receive the immunisation or not). Obviously the experimental design cannot be applied to potential hazards. The best possible studies to assess potential hazards are studies in which *individuals* are selected for a study and specific information is collected on the suspected causal factor, the disease outcome, and (most importantly) other relevant factors which could be related to the disease outcome. Studies comparing health outcomes in two or more groups with different exposures are *cohort* studies (for example, comparing smokers with non-smokers). Studies comparing subjects with a particular disease to an unaffected control group are *case-control* studies (for example, studies of lung cancer patients and unaffected persons assessing differences in past smoking). These are the methods by which most recognised causes of human cancer have been identified (such as smoking, asbestos, ionizing radiation, and so on). Usually, a large number of such studies needs to be completed before a consensus can be reached on a particular causal situation. For radiofrequencies, the studies of individuals are limited to a few cohort studies of certain groups (military personnel, or occupational groups) whose exposure levels are likely to be very different to the general population, and several small case-control studies of particular types of cancer, which have generally poor measures of radiofrequency exposure.

A third type of study is generally acknowledged as being much weaker - that is, much harder to interpret clearly in terms of cause and effect. This is the *ecological study*, where population groups (instead of individuals) are studied and a comparison is made of the frequencies of disease in groups with different exposure levels. Several of the studies relevant to the radiofrequency exposure issue fall into this category, for example, the studies of cancers in relationship to TV or radio transmitters in the UK and in Australia. This type of study is rarely

regarded as definitive. It should lead, however, to more definitive studies of the cohort and case-control type, which are based on observations of selected individuals.

All these types of studies are comparative studies, with control groups, of the exposure in free living human subjects. In general, studies of humans which lack an appropriate control group, such as clinical series, are weaker. Studies which are based on a pre-suspected group or 'cluster' of cases of disease have particular weaknesses. They are generally regarded only as preliminary observations which have to be re-assessed by one of the study types described above. Animal and in vitro experimental evidence is often of high internal validity, but there are usually substantial questions about its relevance to intact humans. Where epidemiological evidence is unclear or is lacking, experimental evidence may be the main way to judge whether the potential exists for health effects of a certain exposure. Elsewhere in this report, aspects of radiofrequency exposures such as tissue penetration and photon energy are discussed; these are relevant to judging the possibility of health effects from the known characteristics of the exposure.

Criteria used in assessing causality

Epidemiological studies usually involve measuring the association between an exposure (such as radiofrequencies) and an outcome (such as cancer). Usually, the results are expressed in terms of relative risk; for example, a relative risk of 1.8 means that the rate of cancer is 1.8 times as high, or 80% increased, in the exposed group. This measures the association; but further assessment is needed to conclude that it is due to causation.

Criteria have been developed which are generally accepted both for the assessment of an individual study, and of the totality of evidence derived from a number of studies. The first process in assessing whether a particular study gives a valid cause and effect assessment is to see if alternative, non-causal, explanations can be reasonably excluded. (This logic in fact applies to all science, including laboratory studies). These non-causal factors are (Elwood 1998):

1. *Observation bias* in the observations which have been made. For example, in a study based on an interview recall of exposures, people affected with cancer may be more ready to recall and report a previous exposure (such as an accidental exposure to radiofrequency sources) than people who have not had cancer. If this bias occurs, even if there is no true relationship between the exposure and cancer, the study will show an (incorrect) positive association (which may be statistically significant).

2. *The effect of other relevant factors*, sometimes known by the term *'confounding'*. For example, if users of mobile phones smoked more than other people, an association between mobile phone use and lung cancer would result.

3. Apparent associations may be due to *chance variation*. This is assessed by statistical methods, which should be applied once observation bias and confounding have been dealt with.

These same influences have to be assessed in the interpretation of studies which show no association, that is, the results give similar rates of disease in exposed and unexposed subjects. A confounding factor can disguise a true association: for instance, an increased risk due to an occupational hazard may be disguised by the generally better health of people selected for employment: the 'healthy worker

effect'; this bias can be dealt with by comparing the workers exposed to the suspected hazard with other workers in the same general situation, but not exposed to that hazard. The size of the study is important; small studies can only show effects which are large. Another problem is the specification of the exposure; for example, if the hazardous effect is restricted to a particular wavelength range, a study in which exposure is defined as any radiofrequency exposure will have reduced ability to detect an effect.

After excluding non-causal explanations, the next process is to look for specific features which would be expected if a biological cause and effect relationship applies. Such criteria are often called the *Bradford Hill criteria* (Hill 1965); they are used by many multidisciplinary international groups in the assessment of cause and effect in health studies. They include an appropriate *time relationship,* which is logically essential: a reasonable *strength* of the relationship; and a *dose-response relationship*. These are helpful mainly in making it easier to detect, and allow for, observation bias and confounding; for example, if a study reports a small relative risk, for example less than 1.5, it may be difficult to ensure that such biases can be excluded. Criteria of *specificity of effect, plausibility, and coherence* are sometimes useful.

Consistency is the most important criterion and is assessed in two ways: as consistency within a study, and, the most important criterion of all, consistency among various studies. In the great majority of situations the development of a consensus amongst the scientific community on whether a particular agent causes (for example) cancer is based on a consideration of the consistency of evidence from a large number of studies of different designs and in different populations, which overall produce a substantial body of evidence. This requires that all relevant studies be considered. This is made more difficult by the effects of publication bias, that is, not all studies have an equal chance of being published; studies which have negative results, are in accord with conventional assumptions and therefore are not news worthy, or in contrast give unexpected results which are not accepted by reviewers, may have difficulty being published.

The main result is usually expressed as a measure of association, the *relative risk*, which is the risk of disease in people exposed to the factor under consideration, as a ratio of the risk in those people not exposed. For example, a relative risk of 1.5 means that the study is estimating that people exposed to the factor under consideration have 1.5 times the disease risk of those not exposed; this could also be expressed as a 50% increase; a relative risk of 1 means that there is no association, and a relative risk of less than one equates to a protective effect. This result (the relative risk) is the *size of the association* provided by the study. The accuracy or statistical precision of that estimate is shown by *confidence limits*. These are usually expressed as '95% confidence limits', meaning that in statistical terms there is a 95% probability (95 chances in 100) that the true result will be within that range. A small study, because it is imprecise, will have wide confidence limits. A larger study will have narrower confidence limits; that is, the estimate is much more precise. If the confidence limits include the value of 1.0, the study is said to be '*not statistically significant*', in other words, it is still compatible with no association and a relative risk of 1.0. If the confidence limits are all higher than 1.0, it means that the study shows an increased risk or a positive association which in technical terms is '*statistically significant*'.

If radiofrequencies do cause a disease like cancer, a good study will show this by giving a relative risk greater than one. If the study is large enough, the 95% confidence limits will also be above one: a hypothetical example would be a relative risk of 1.5, with limits of 1.2 to 1.8. This result would be described as showing an increased risk, which is statistically significant. Even this result does

not mean that a cause and effect relationship has been shown: that depends on whether the study is free of biases in the data used, and on whether other explanations such as the effects of related factors have been taken into account.

If, on the other hand, radiofrequencies do not cause (or prevent) the disease, a good study will give a relative risk close to one. However, it is unlikely that the relative risk will be precisely one, because of the impossibility of collecting perfectly accurate data and having no influences of other factors, and also because of the effects of chance variation. The 95% confidence limits will usually include the value of 1.0: a hypothetical example would be a relative risk of 1.1, with limits of 0.8 to 1.3. This result would be described as showing no increased risk (or only a small increased risk), which is not statistically significant. A study with a relative risk of for example 3.0 with confidence limits of 0.5 to 18.0 is however difficult to interpret as it gives a non-significant result, but shows an association; fundamentally, the study is very imprecise as it is too small.

The reported relative risk and its confidence limits depend on the association seen, the size of the study and the statistical methods used. They do not assess whether the observations have been collected without bias, or whether the association is due to factors other than the one suspected, except where these have been dealt with in the study design or analysis. These issues have to be addressed by a careful review of the study.

It is impossible to prove, with absolute certainty, the *absence* of an effect. To prove with certainty that radiofrequency energy, or any other aspect of the human environment, is completely safe is impossible; as to do so requires proof of the absence of any association between exposure to radiofrequencies and any one of an infinite number of health outcomes. This logical difficulty is expressed in the general approach of epidemiology, and science in general, which accepts as 'fact' not something which has been proven with absolute certainty, but as the best current explanation of the available results of scientific studies. Scientific studies are designed not to give 'proof', but are designed to disapprove or 'falsify' the current hypothesis or accepted viewpoint on an issue. If well performed scientific studies of strong design are carried out and fail to disprove the hypothesis, the hypothesis becomes stronger, that is gains more validity and is more likely to be true, but it never reaches the point of being 'proven' with absolute certainty.

If the balance of the available evidence overall is that health effects have not been demonstrated, despite some studies of reasonable quality having been done, then the likelihood that radiofrequency exposures are safe is increased. The evidence pointing to safety may well be sufficient so that the community will accept the evidence as sufficient to allow normal activities based on the assumption of safety.

It follows from this that a claim that health effects, even if not demonstrated, remain possible will always be true. But because it is always true, it is not very helpful. The claim that health effects may exist is of no value unless it is based on some evidence either of the existence of such effects, or of other scientific evidence which make such effects likely, rather than just possible.

Epidemiological studies of cancer up to 1999

Epidemiological studies relating radiofrequency exposures and cancers have been reviewed in the reports by ICNIRP (1998), the Royal Society of Canada (1999), and the Stewart Report (Independent Expert Group on Mobile Phones [IEGMP] 2000), and in publications by Elwood (1999) and by Bergqvist (1997), amongst

others. Studies published up to 1999 are reviewed in detail in Elwood (1999), and will be briefly summarised here.

The studies fall into five groups: studies of clusters of cases, studies of general populations exposed to television, radio and similar sources; studies of occupational groups; case control studies, and studies of users of cell phones. Cluster studies are inherently difficult to interpret because of the impossibility of assessing the effects of chance variation if the study is performed after a cluster has been identified in an anecdotal way. Cluster studies should be regarded as raising a hypothesis, which can then be tested in further studies. The situation where this has been done is in regard to the Sutton Coldfield FM radio and UHF-TV transmitter in the United Kingdom, where after the observations of a doctor, a cluster of leukaemias and lymphomas in adults living close to the transmitter was noted, although the authors correctly conclude that no causal inference can be drawn from a cluster investigation alone (Dolk et al. 1997b).

In response to this however, these authors carried out studies of the distribution of other types of cancer around the Sutton Coldfield transmitter, and studies of all types of cancer around 20 other transmitters in the United Kingdom, giving an appropriate hypothesis testing investigation (Dolk et al. 1997a). In general this showed negative results, although a weak trend towards a decrease in rates of adult leukaemia with increasing distance from the transmitter was seen, of borderline statistical significance. The trend was inconsistent in that there was no excess risk living closest to the transmitter. The authors suggested that if this reflected a true association, a simple radial decline exposure model was not sufficient to explain it, and regarded their studies as giving only weak support to the previous cluster based hypothesis.

In a study in Sydney, Hocking et al. (1996) showed increased incidence and mortality rates of childhood leukaemia in the aggregate of three local authority areas close to a VHF-TV transmitter, compared to a number of areas further away. A further analysis by individual local government area showed that the excess applied only to one of the three inner areas (McKenzie, Yin, & Morrell 1998); the interpretation is disputed (Hocking, Gordon, & Hatfield 1999). An earlier study of childhood cancer in San Francisco showed no geographical association with a transmitter described as a microwave tower (Selvin, Schulman, & Merrill 1992).

There have been several studies of occupational groups. A study in the Polish military showed substantial excesses of total cancer and of several sub-types of cancer (Szmigielski 1996), but questions have been raised about possible bias in exposure information in the study (Bergqvist 1997; Elwood 1999; IEGMP 2000), and the results are inconsistent with those of other studies. An earlier study based in the US Navy showed no clear increase in cancer in exposed personnel, although the control group were also likely to have been exposed to some extent (Robinette, Silverman, & Jablon 1980). Studies of US amateur radio operators showed an excess in one of nine types of leukaemia assessed, although other types of exposure may be confounding (Milham 1988). A study of female radio and telegraph operators working at sea showed an excess of breast cancer and uterine cancer, and again the influence of other confounding factors may be relevant (Tynes et al. 1996). A detailed study of electrical workers in Quebec and France showed an excess of lung cancer, but their exposures were not primarily to radiofrequencies (Armstrong et al. 1994).

There have been a considerable number of case control studies of particular types of cancer, in which radiofrequencies have been one of usually a large number of potential exposure factors which have been addressed. One study showed an

association between likely radiofrequency exposures and brain cancers in US Air Force personnel (Grayson & Lyons 1996). A study in US civilians showed an excess only for the combination of radiofrequency exposures and other electrical or electronic job exposures, but not with radiofrequency alone (Thomas et al. 1987). Other studies show excesses which are inconsistent in terms of the method of collecting the information, or are non-significant or open to problems of multiple testing (Cantor et al. 1995; Demers et al. 1991; Hayes et al. 1990; Holly et al. 1996).

Epidemiological studies of cancer published since 1999

Earlier studies of cancer are included in the review paper by Elwood (1999).

Studies of cancer in association with the use of cellular telephones

Overall mortality of cell phone users

In the U.S., a cohort of over 255,000 persons who were customers of a telephone company in 1993-94, in four urban areas, were identified from telephone company records (Rothman et al. 1996a). Of these, 65% were men, and the median age was 42 years in men, 41 in women. Deaths in one year, 1994, were obtained by data linkage. The object was to compare death rates for customers with 'portable' phones (cell phones) with rates for customers with 'mobile' phones, which here means the older type of transportable bag phones with the antenna separate from the hand piece, on the basis that the 'portable' phone (the modern cell phone) will have more head exposure to radiofrequencies. This study was published to show the methods for proposed further studies. The data show age-specific death rates to be similar for users of the two types of telephones. For customers with accounts at least 3 years old, the ratio of mortality rates in 1994 for 'portable' telephone users, compared with transportable telephone users, was 0.86 (90% confidence interval 0.47-1.53); that is their overall mortality was not significantlfy different. The numbers of deaths due to brain tumours and leukaemias were small, but there was no increased risk with greater use of hand held phones (Dreyer, Loughlin, & Rothman 1999). However, the short follow up time does not allow assessment of longer term effects.

Case-control study of brain tumours and the use of cellular telephones: Hardell et al.

In this Swedish study (Hardell et al. 1999), 209 subjects with pathologically verified brain tumours living in two areas in 1994-96 were included, with 425 controls from the Swedish Population Register, matched for sex, age and study region. Exposure was assessed by questionnaires supplemented by telephone interviews. The response rates given in the paper are 90% for cases, 91% for controls, but this is only for the invitation to interview. Of 262 cases identified, 209 (80%) are in the study, but only 198 (76%) are included in the detailed tables. Ever-use of a cellular telephone showed no association, (odds ratio 0.98 95% confidence interval 0.69 – 1.41). Dose-response assessment and use of different tumour induction periods gave similarly no associations, even at the highest level of use and latency period (over 968 hours of use, and over 10 years). An analysis restricted to tumours occurring in the temporal or occipital lobe of the brain, and on the same side as the reported use of the cellular phone gave non-significantly increased risks; right side odds ratio 2.45, (confidence interval 0.78-7.76), left side odds ratio 2.40, (confidence interval 0.52-10.9), based on 8 and 5 cases respectively. This comparison comes from a table involving 26 comparisons.

The authors state that an increased risk was found only for use of the analogue system, but they had few data on digital GSM phones. The authors concluded, *'An increased risk for brain tumour in the anatomical area close to the use of a cellular telephone should be especially studied in the future.'* In a later paper based on the same study (Hardell et al. 2000) the authors present the same data in a different way with further analysis. They show a marginally significant increased risk for tumours in the temporal, occipital, or temporoparietal regions, where cell phone use was on the same side: relative risk 2.62 (95% confidence limits 1.02 – 6.71) after multivariate analysis. They also show several other factors as showing statistically significant associations: occupation as a physician, in laboratory work, or in the chemical industry, and exposure to diagnostic radiology of the head and neck region.

The Stewart Report (IEGMP 2000) and the Royal Society of Canada (1999) concluded that the results of the Swedish study could easily have occurred by chance. It has also been argued that the study used incomplete ascertainment of cases (Ahlbom & Feychting 1999).

Case-control study of brain tumours and the use of cellular telephones: Muscat et al.

Muscat et al. (2000) did a case control study, comparing patients with primary brain cancer identified at five referral centres in the U.S. to inpatient controls in the same hospital, with either benign conditions or cancer, excluding lymphoma or leukaemia. Controls were matched by hospital, age, sex, race, and month of admission. There were 469 cases, being 82% of those approached for interview, but 70% of all those eligible. The response rate in the controls was 90%.

The primary question was whether patients had ever used a hand-held cellular telephone on a regular basis, defined as having had a subscription to a cellular telephone service. The overall frequency of ever-use of hand held cellular telephones was 14.1% in cases and 18.0% in controls. Relative risks by the number of years of use (up to 4 or more), number of hours per month (up to 10 or more), and number of cumulative hours (up to 480 or more), showed no excess risks and no significant trends. The relative risk in the highest exposure groups by each measure of intensity of exposure was 0.7; and a non-parametric regression curve showed that most high usage groups had a slightly reduced relative risk.

In this study, 80% of cell phones used were analogue. In normal use, the maximum energy absorption is in the temporal lobe, and also the frontal and parietal lobes (Rothman et al. 1996b). The analysis was done separately for different locations of tumours, each compared to all controls with multivariate analysis for confounders, and showed no significant associations with any site, with the relative risk for occipital lobe tumours being 0.8, temporal lobe 0.9, parietal lobe 0.8, and frontal lobe 1.1. Sub-division by pathological type showed no significant associations, although the risk for neuroepitheliomatous tumours was 2.1 (95% limits 0.9 - 4.7), based on 35 cases. Information on the laterality of cellular telephone use was obtained for 56 of the 66 cases with brain cancer. Of 41 cases who specified laterality and had a localised tumour, 25 reported ipsilateral relationships, and 15 contralateral relationships, (P = 0.06). Of the fourteen cases with temporal lobe cancer that used cellular telephones, 5 were ipsilateral and 9 contralateral (P = 0.33).

In summary this substantially large study shows no excess risks, even for the specific locations of tumours which were highlighted in the previous case control study (Hardell et al. 1999; Hardell et al. 2000) . The interviews were carried out by 'health professionals or health professionals in training', which is often not

ideal, as dedicated interviewers employed for the purpose are usually more reliable. The interviews lasted about half an hour, which suggests they were fairly superficial. The study covers a restricted time period. However, despite these limitations it is a useful study. The authors' conclusions are *'Our data suggest that use of handheld cellular telephones is not associated with risk of brain cancer, but further studies are needed to account for longer induction periods, especially for slow-growing tumours with neuronal features'* (Muscat et al. 2000).

Case-control study of brain tumours and the use of cellular telephones: Inskip et al.

A further U.S. case control study involved 782 patients and 799 hospital controls with non-malignant conditions (Inskip et al. 2001). Patients had a primary brain cancer diagnosed between 1994 and 1998, and 92% of eligible patients agreed to participate, along with 86% of controls, who were matched by hospital, age, sex, race or ethnic group, and proximity of their residence to the hospital. A computer assisted personal interview was carried out by a research nurse, using proxy interviews for subjects who were too ill or functionally impaired, which applied to between 3 and 16% of different categories of cases, and 3% of controls.

Of the cases, 39.5 % reported ever using a mobile phone, compared to 44.9 % of controls; 17.8 % of cases and 21.6 % of controls reported 'regular use'. The relative risk associated with use of a cellular telephone for more than 100 hours was 1.0 (95% limits 0.6 - 1.5) for all brain cancers, and 0.9 for glioma, 1.4 for acoustic neuroma, and 0.7 for meningioma; all non-significant. There was no evidence that the risks were higher with use of 1 hour or more per day, or use for 5 or more years. There was no association between laterality of telephone use and laterality of brain tumour, no increased risk for temporal, parietal or frontal lobe tumours, and no increased risk with specific subtypes of tumours. In contrast to the study by Muscat et al. (2000) the risk for neuroepitheliomatous tumours was 0.5 (95% limits 0.1 – 2.0), based on 25 cases. The authors conclude that *'These data do not support the hypothesis that the recent use of hand-held cellular phones causes brain tumours, but they are not sufficient to evaluate the risks among long-term, heavy users and for potentially long induction periods'* (Inskip et al. 2001).

An accompanying editorial (Trichopoulos & Adami 2001) comments that the limitations to the study are that the findings apply to predominantly analogue phones, do not assess risks which may occur after a considerable latency period, and cannot confidently exclude minor increases such as relative risks less than 1.5.

Study of ocular melanoma and use of mobile phones

A case control study of uveal melanoma assessed occupation in terms of likely radiofrequency exposure (Stang et al. 2001). The analysis combines two small studies; one in 1994 to 1997, in five different regions of Germany, with population based controls, based on mandatory lists of residents (37 cases, 327 controls), and an additional study based on one hospital, with controls seen in the same department with 'newly diagnosed benign disease of the posterior eye segment', excluding occupational accidents involving the eye (81 patients, 148 controls). The response rates for ocular cancer patients were 84% in the population based study and 88% in the hospital based study, and for the controls were 48% in the population based study and in the hospital based study 79%.

Data were collected by an interview taking around 70 minutes, which explored details of occupational history; non-occupational sources of radiofrequencies were not assessed. The relevant question on these was *'did you use radio sets, mobile phones, or similar devices at your work place for at least several hours per day?* ', with further details requested if the reply was 'yes'.

There was a significant association with radio sets or mobile phones, odds ratio 3.0, (95% confidence limits 1.4 to 6.3), based on 16 cases (13.6%) and 46 controls (9.7%) rated as exposed to radiofrequencies defined by the question given above, at their jobs for at least 6 months and several hours per day. The association was seen both in the population based study (odds ratio 3.2) and in the hospital based study (odds ratio 2.7). Further analysis showed that the elevated risk was similar in those who had been exposed for a short time or for longer. Occupations were categorised as having 'possible', or 'probable or certain', mobile phone exposure. The risk for the 'probable or certain' category was 4.2 (95% confidence limits 1.2 - 14.5), but this was based on only 6 cases. The odds ratio for those exposed to radio sets was 3.3 (95% confidence limits 1.2 - 9.2) based on 9 cases; these exposures included walkie-talkies in military and security services, and radio sets on ships, police cars, and similar. Control for iris and hair colour did not change the results substantially, but there was no consideration of exposure to ultraviolet radiation (Inskip 2001). This preliminary study requires confirmation.

General population cohort study of cellular telephone users in Denmark

Johansen et al. (2001a) carried out a prospective cohort study in Denmark, using the computerised files of the two Danish operating companies. From a total of over 720,000 subscribers some 200,000 corporate customers had to be excluded because information on individuals was not available, and after further exclusions because of errors in name, address, duplications, etc. there were 420,095 cellular telephone subscribers identified, being 80.3% of the original list of residential subscribers. Follow up was from the date of first subscription up to December 31, 1996, and rates were compared to national rates adjusted for age, sex and calendar period. Of the total cohort, most were men (357,000), most were aged 18 – 29 at first subscription, and the year of first subscription was from 1982 to 1995, with 70% being in 1994-95 and 23% in 1991-93; 58% used a digital GSM system at first subscription, with the remainder having an analogue NMT system.

The standardised incidence ratios are presented by gender, and for all cancers were 0.86 (95% confidence limits 0.83–0.90) in men, and 1.03 (confidence limits 0.95–1.13) in women, based on 2876 and 515 cases of cancer respectively. For men, the incidence ratios of most smoking related cancers were reduced, while testicular cancer was non-significantly elevated (incidence ratio 1.12, 95% limits 0.97–1.30). For women, the variations were greater as they were based on smaller numbers, and there were no significant differences; the incidence ratio for breast cancer was 1.08 (limits 0.91–1.26). Tumours of the central nervous system, and leukaemia, were examined in more detail. The overall incidence ratio, both sexes combined, was 1.0 for each of these, and there were no trends apparent with latency up to 5 or more years, with age at first subscription, and no differences seen between analogue and digital telephones. There was no association with site of tumour within the brain, with tumours of the temporal lobe having an incidence ratio of 0.86, frontal lobe 1.11, and parietal lobe 0.48, all non-significant. There was no increase in salivary gland tumours or leukaemia.

There was no control for socioeconomic status or other covariates, and the pattern of incidence ratios is consistent with a distribution of mobile phone use characterised by higher socioeconomic status, and as a correlate, a lower rate of smoking. The study was not able to assess intensity of use, as records on number

of calls made or length of call were not useable, and the follow-up was up to 15 years, although the average period of follow-up was only 3.1 years. However, it provides considerable evidence against any large increase in risk within several years of use.

The authors comment that *'Conceivably, the latency may be too brief to detect an early stage effect or an effect on the more slowly growing brain tumours. Moreover our study may currently have too few heavy users to exclude with confidence a carcinogenic effect on brain tissue following intensive, prolonged use of cellular telephones. On the other hand, if RF exposure is assumed to act by promoting the growth of an underlying brain lesion, then the intense recent use, as currently experienced by large numbers of our cohort, might be of more importance than latency or long-term use considerations. '* (Johansen et al. 2001a). In an accompanying editorial, Park (2001) notes that the study is strong because of its population base and size, and comments that the evidence suggesting that radiofrequencies could have a carcinogenic effect is very slim, making an analogy with previous concerns about low frequency fields which were allayed by a high quality case control study.

In correspondence, Hocking (2001) has emphasised the exclusion of corporate customers, and the lack of information on intensity of use, and also suggested that the increased risk of testicular cancer (relative risk = 1.12, 96% limits 0.97 – 1.30) could be related to exposure by carrying a phone on the belt. The authors respond that corporate customers may be an important high exposure group, but any bias produced by their exclusion would almost surely be small, and they feel that it is unlikely there would be any substantial radiofrequency exposure from cellular phones worn on a belt or in a pocket (Johansen et al. 2001b). Godward et al. (2001) questioned the use of the whole population reference group rather than an unexposed group, which could lead to an underestimate of effect, and also emphasise the limited data on exposure intensity, dose response effects, and socioeconomic status, and the limited length of follow-up. The authors responded that the underestimation of effect by the choice of control group would be very small, and agree with the limitations in terms of length of follow-up. They argue that confounding by socioeconomic status would be unlikely to be a major issue in Denmark, although linkage to such information is planned in the future (Johansen et al. 2001c) and point out that the study had sufficient power to rule out moderate or high risks within a short follow-up period (Johansen et al. 2001b). Hardell and Mild (2001) ask for specific analyses for tumours of the temporal and occipital lobe, after a 5 year latency period, distinguishing analogue from digital phones. The authors comment (Johansen et al. 2001c) that even in this large study of 420,000 subjects, an analysis stratified by subsite, latency period and type of telephone would have insufficient numbers to be informative.

Occupational studies

Cohort study of mortality of US Motorola employees

A cohort study of mortality has been conducted (Morgan et al. 2000) of all US Motorola employees with at least six months employment at any time between 1 January 1976 and 31 December 1996, with follow up to 31 December 1996. This study included 195,775 workers, of whom 44% were women, and of whom 6,296 died during the follow up period.

Likely radiofrequency (RF) exposures from job positions were based on the business sector, work site, job description, and calendar period; each of 9,724 job titles were classified into one of four exposure groups in terms of likely RF

exposure, described as background, low, moderate and high. RF exposure sources were classified into different groups in terms of power, from background exposure up to 50+ W, and the relative level of likely radio frequency exposure for the four groups defined above was given as 0, 1, 6 and 100. Examples of classification of jobs are given; unexposed workers included administrative and support personnel, low RF exposure included assemblers and operators not directly involved with RF technologies, moderate RF exposures included those who routinely used hand-held radios or worked with RF product development, and high RF exposure included technicians, testers and engineers involved with RF product testing.

In the analysis, worker's exposure assignments were classified in three different ways: in terms of their usual assignment relating to the job they held longest while at Motorola, their peak assignment reflecting the job with the highest expected RF level, and a cumulative exposure score based on the summation of the RF level multiplied by the duration of employment for each job throughout the employee's work history at Motorola.

A comparison of the mortality of the workforce with the mortality rates expected for a general US population, showed a mortality ratio for all causes of 0.66, and for all cancers of 0.78, both significantly reduced. This is characteristic of the 'healthy worker effect'. Of 60 specific causes of death assessed, the highest standardised mortality ratio (SMR) was 1.28, and only five of the 60 were greater than one. For all employees, SMR's for cancers of the lymphatic / haemopoetic system, and also those of the central nervous system, were both significantly reduced from the expected rates, with SMR's of 0.77 (95% confidence limits 0.67 – 0.89) and 0.60 (limits 0.45 – 0.78) respectively. SMR analyses were also carried out for the 24,621 subjects who were classified as moderate to high RF exposure by peak exposure classification, which showed somewhat lower SMR's for cancers of the central nervous system and brain cancer (SMR 0.53, limits 0.21 – 1.09), and for all lymphomas and leukaemias (SMR 0.54, limits 0.33 – 0.83).

The more powerful analyses are the comparisons within the Motorola employees, comparing those with higher radiofrequency exposures with the lower exposed or unexposed categories. Comparisons were based on each of the usual exposure and the peak exposure classifications, comparing the categories of high, moderate, and low exposures to the 'no exposure' group. Results are also presented looking at duration of exposure, latency (that is allowing for a lag time between the first time of exposure and death), and looking at men and women separately.

Detailed analyses are presented for cancers of the brain, all lymphatic and haemopoetic cancers, leukaemia, non-Hodgkin's lymphoma, and Hodgkin's disease. None of the results suggested any increased risk. The relative risk for the high exposure category, based on usual exposure, for brain cancer was 1.07 (95% confidence limits 0.32 – 2.66), for lymphatic and haemopoetic cancers was 0.70 (limits 0.27 – 1.47), for leukaemia was 0.99 (limits 0.39 to 2.09), and for non-Hodgkin's lymphoma was 0.58 (limits 0.12 – 1.74). For Hodgkin's disease there were no cases in the highest exposure category, but for those in the moderate exposure category for usual exposure the relative risk was 3.20 (limits 0.73 – 10.4) based on three cases. There was no excess risk comparing those above the median exposure with those with no exposure (relative risk 0.95).

The authors point out that this study is limited by the qualitative job exposure matrix (rather than the ideal of having actual exposure measurements on each subject). It is also limited by the relatively young age of the cohort, with the result

that the numbers of deaths from specific causes are small, despite the large size of the occupational group. They conclude that *'The lack of elevated mortality risk for brain cancers and all lymphatic/haemopoetic cancers combined suggests that occupational RF exposure, at the frequencies and field levels experienced within this cohort, are not associated with an increased risk for these diseases'* (Morgan et al. 2000, p. 124). They state *'the occupational RF levels amongst Motorola workers are lower than military and plastics manufacturing workers'* (Morgan et al. 2000, p.126). They conclude that their findings are not compatible with excess risks of 3 or greater for brain cancers, lymphomas or leukaemias, and note *'We did not observe indications of excess relative risk, but we cannot rule out the possibility of potential effects in the range of 1.5-2.0 relative risk'* (Morgan et al. 2000, p.126).

These results do not suggest any general increased mortality risk, and show no evidence of an increase in any specific cancer, although a small increase (or decrease) cannot be excluded. There is no association between the highest levels of radiofrequency exposures experienced and the cancers that were intensively studied, that is brain cancers, leukaemias, and lymphomas. Even a study of this size cannot confidently exclude a modest increased risk of specific cancers, which occur in relatively small numbers, although it can confidently exclude increases in total mortality or from major causes such as all cancer. The exposure information is very limited; the likely exposures of the various groups of workers are not defined. If an effect were specific to a particular type of radiofrequency exposure, the study would have less ability to detect it.

Cohort study of plastic-ware manufacturing workers exposed to radiofrequency sealers

This study (Lagorio et al. 1997) was based on a plastic-ware manufacturing plant in Grosseto, Italy, and compares operators of radiofrequency sealers (302 women and 4 men), other labourers, and white-collar workers. A survey carried out in the 1980's showed that the recommended exposure limit of 10 W/m^2 equivalent power flux density was frequently exceeded in this factory mainly due to high electric field strengths. These workers were also exposed to solvents, and to vinyl chloride monomer, an established carcinogenic agent. The analysis, restricted to women, is based on only 9 observed deaths amongst radiofrequency sealer operators, compared to 6.3 expected. The excesses were seen in accidents and violence (2 observed, 0.8 expected, standardised mortality ratio, SMR, 2.4) and malignant neoplasms, (6 observed, 3 expected, SMR 2.0, 95% confidence interval 0.7 – 4.3). The authors' conclusion is *'This study raises interest in a possible association between exposure to RF radiation and cancer risk. However, the study power was very small, and the possible confounding effects of exposure to solvents and vinyl chloride monomer could not be ruled out'* (Lagorio et al. 1997). The results cannot be interpreted clearly without further relevant studies.

Case-control study of brain cancer in Israel

In this study (Kaplan et al. 1997), 139 patients with primary brain tumours in Israel from 1987 to 1991 were compared to controls in terms of lifetime occupational history, assessing many occupational categories. Amongst several categories, 'electric and electronics manufacture, and communication' is given, with 8 cases only, and no significant increased risk. For malignant brain tumours, based on only 4 cases, the odds ratio was 2.2 (95% confidence interval 0.5 – 9.3). Another breakdown separating out 'telephone and radio operators and electricians' give a risk of 1.2 for all brain tumours based on three cases (95% confidence interval 0.3 – 5.2). This small study is basically uninformative for radiofrequencies.

Cohort study of Canadian police officers

This study (Finkelstein 1998) does not include any data on radiofrequency exposure, but is relevant to an earlier cluster study of testicular cancer in police officers (Davis & Mostofi 1993). In Ontario, for 20,601 male officers, the overall cancer incidence ratio, compared to the general population, was 0.9 (90% confidence interval 0.83 – 0.98); there was a reduced rate of lung cancer (0.66), and an increased rate of melanoma (1.45, 90% limits 1.10 – 1.88). The rate of testicular cancer was non-significantly increased, ratio 1.3, 90% limits 0.89 – 1.84), based on 23 cases. There was no information on the use of radar equipment.

Further study of cancer in relationship to radio and television transmitters

A further study on cancer incidence in residents living close to the Sutton Coldfield transmitter in England (Cooper, Hemmings, & Saunders 2001) was carried out using cancer data for the years 1987-94, and the same methods as in the earlier studies. The only site showing a marginally significant decline with distance was leukaemia in male children, based on 15 cases including only one within two kilometres distance. There were small increases in risk in several types of adult leukaemia, but no significant declines in risk with distance. The findings on the original Sutton Coldfield study were not replicated.

Studies of reproductive outcomes

Several studies have assessed reproductive outcomes in female physiotherapists who used diathermy units emitting short wave radiation (27 MHz) or microwave radiation (915 or 2450 MHz). These include a Swedish study of congenital malformations and perinatal death (Kallen, Malmquist, & Moritz 1982), two Danish studies (Larsen 1991; Larsen, Olsen, & Svane 1991), a Swiss study (Guberan et al. 1994) to assess the results of Danish studies, a Finnish study (Taskinen, Kyyronen, & Hemminki 1990), and a US study of spontaneous abortion (Ouellet-Hellstrom & Stewart 1993).

These studies show little consistency in their results. Consistency would be expected if real associations were being uncovered, as the studies are all very similar, all being based on physiotherapists exposed to EMF emitting equipment in their work. The methods of determining pregnancy outcomes and exposures are very similar in all the studies. A considerable number of different outcomes have been looked at. The studies together do not show any clear association between EMF exposures in female physiotherapists during pregnancy and either congenital malformations or spontaneous abortions.

There have been no studies of birth outcomes in regard to paternal exposure to radiofrequencies.

The Schwartzenberg studies

These concern a large short wave radio transmitter in Switzerland. These studies have not been published, but have been reported in detail (Altpeter et al. 1995). Questionnaire studies showed increased rates of self-reported symptoms in subjects living closer to the radio transmitter, particularly in regard to sleep disturbance. Studies in which the transmitter was turned off or changed in direction to reduce exposure showed, on complex statistical analysis, a modest but significant improvement in self-reported sleep patterns associated with lower

exposures. A study assessing melatonin excretion showed no changes in melatonin. These studies are difficult to interpret because of the subjectivity in the symptoms reported, possible knowledge about changes in the transmissions, and the potential for bias due to concern about radiofrequencies rather than a physical effect. Experimental studies of exposure to cell phone frequencies on sleep patterns in volunteers have given mixed results.

The Skrunda studies

Studies of motor and psychological functions in school children living near a radar station in Latvia are also difficult to interpret, because of lack of information on the measurement methods used (Kolodynski & Kolodynska 1996). For example, there were substantial differences between children in two different areas both with low background level of radiofrequency emissions, as well as differences between these children and those in the higher exposure area.

Other relevant human studies

There have been several experimental studies of the effect of radiofrequency emissions from a mobile phone type system on sleep patterns, which have not given consistent results (Mann & Röschke 1996; Röschke & Mann 1997; Wagner et al. 1998). Studies of pituitary hormone production have shown no major changes (de Seze, Fabbroperay, & Miro 1998), and a study of 37 young male volunteers showed no disruption of the melatonin circadian profile after exposure to 900 or 1800 MHz mobile phones for 2 hrs per day, 5 days per week, and 4 weeks (de Seze et al. 1999). Several complex studies of aspects of cardiovascular function have produced results which are unclear in terms of their clinical significance (Bortkiewicz et al. 1995; Bortkiewicz et al. 1997; Bortkiewicz, Gadzicka, & Zmyslony 1996).

An experimental study in 10 volunteers (Braune et al. 1998) used a GSM mobile telephone placed on the right-hand side of the head and operated by remote control. Placebo exposure was always given before radiofrequency exposure; this aspect of the design has been criticised (Reid & Gettinby 1998). There were no statistically significant effects of radiofrequencies on subjective parameters of well-being, although these are not described in any detail. Systolic and diastolic blood pressures were higher during radiofrequency than during placebo exposure; 35 minutes exposure gave an increase of 5 to 10 mm in blood pressure. The result is of interest, but needs to be assessed by other studies.

References

Ahlbom, A. & Feychting, M. 1999, 'Re: Use of cellular phones and risk of brain tumours: a case-control study', *International Journal of Oncology*, vol. 15, p. 1045.

Altpeter, E. S., Krebs, Th., Pfluger, D. H., von Känel, J., Blattmann, R., Emmenegger, D., Cloetta, B., Rogger, U., Gerber, H., Manz, B., Coray, R., Baumann, R., Stärk, K., Griot, C. & Abelin, T. 1995, *Study on health effects of the shortwave transmitter station of Schwarzenburg, Bern, Switzerland (Major report)* , BEW Publication Series Study No. 55, Bundesamt fur Energiewirtschaft (Federal Office of Energy), Bern Switzerland.

Armstrong, B., Theriault, G., Guenel, P., Deadman, J., Goldberg, M. & Heroux, P. 1994, 'Association between exposure to pulsed electromagnetic fields and cancer in electric utility workers in Quebec, Canada, and France', *American Journal of Epidemiology*, vol. 140, no. 9, pp. 805-820.

Bergqvist, U. 1997, 'Review of epidemiological studies,' in *Mobile Communications Safety*, eds N. Kuster, Q. Balzano & J.C. Lin, Chapman & Hall, London UK, pp. 147-170.

Bortkiewicz, A., Gadzicka, E. & Zmyslony, M. 1996, 'Heart rate variability in workers exposed to medium-frequency electromagnetic fields', *Journal of the Autonomic Nervous System*, vol. 59, no. 3, pp. 91-97.

Bortkiewicz, A., Zmyslony, M., Gadzicka, E., Palczynski, C. & Szmigielski, S. 1997, 'Ambulatory ECG monitoring in workers exposed to electromagnetic fields', *Journal of Medical Engineering and Technology*, vol. 21, no. 2, pp. 41-46.

Bortkiewicz, A., Zmyslony, M., Palczynski, C., Gadzicka, E. & Szmigielski, S. 1995, 'Dysregulation of autonomic control of cardiac function in workers at AM broadcasting stations (0.738-1.503 MHZ)', *Electro- and Magnetobiology*, vol. 14, no. 3, pp. 177-191.

Braune, S., Wrocklage, C., Raczek, J., Gailus, T. & Lücking, C. H. 1998, 'Resting blood pressure increase during exposure to a radio-frequency electromagnetic field', *Lancet*, vol. 351, pp. 1857-1858.

Cantor, K. P., Stewart, P. A., Brinton, L. A. & Dosemeci, M. 1995, 'Occupational exposures and female breast cancer mortality in the United States', *Journal of Occupational and Environmental Medicine*, vol. 37, no. 3, pp. 336-348.

Cooper, D., Hemmings, K. & Saunders, P. 2001, 'Re: Cancer incidence near radio and television transmitters in Great Britain I. Sutton Coldfield transmitter II. All high power transmitters', *American Journal of Epidemiology*, vol. 153, no. 1, pp. 202-205.

Davis, R. L. & Mostofi, F. K. 1993, 'Cluster of testicular cancer in police officers exposed to hand-held radar', *American Journal of Industrial Medicine*, vol. 24, pp. 231-233.

de Seze, R., Ayoub, J., Peray, P., Miro, L. & Touitou, Y. 1999, 'Evaluation in humans of the effects of radiocellular telephones on the circadian patterns of melatonin secretion, a chronobiological rhythm marker', *J Pineal Res*, vol. 27, pp. 237-242.

de Seze, R., Fabbroperay, P. & Miro, L. 1998, 'GSM radiocellular telephones do not disturb the secretion of antepituitary hormones in humans', *Bioelectromagnetics*, vol. 19, no. 5, pp. 271-278.

Demers, P. A., Thomas, D. B., Rosenblatt, K. A., Jimenez, L. M., McTiernan, A., Stalsberg, H., Sternhagen, A., Thompson, W. D., McCrea Curnen, M. G., Satariano, W., Austin, D. F., Isacson, P., Greenberg, R. S., Key, C., Kolonel, L. N. & West, D. W. 1991, 'Occupational exposure to electromagnetic fields and breast cancer in men', *American Journal of Epidemiology*, vol. 134, no. 4, pp. 340-347.

Dolk, H., Elliott, P., Shaddick, G., Walls, P. & Thakrar, B. 1997a, 'Cancer incidence near radio and television transmitters in Great Britain 2: All high power transmitters', *American Journal of Epidemiology*, vol. 145, no. 1, pp. 10-17.

Dolk, H., Shaddick, G., Walls, P., Grundy, C., Thakrar, B., Kleinschmidt, L. & Elliott, P. 1997b, 'Cancer incidence near radio and television transmitters in Great Britain 1. Sutton Coldfield transmitter', *American Journal of Epidemiology*, vol. 145, no. 1, pp. 1-9.

Dreyer, N. A., Loughlin, J. E. & Rothman, K. J. 1999, 'Cause specific mortality in cellular telephone users', *JAMA*, vol. 282, pp. 1814-1814.

Elwood, J. M. 1998, *Critical Appraisal of Epidemiological Studies and Clinical Trials*, 2nd edn, Oxford Univ Press, Oxford UK.

Elwood, J. M. 1999, 'A critical review of epidemiologic studies of radiofrequency exposure and human cancers', *Environmental Health Perspectives*, vol. 107, supplement 1, pp. 155-168.

Finkelstein, M. M. 1998, 'Cancer incidence among Ontario police officers', *American Journal of Industrial Medicine*, vol. 34, pp. 157-162.

Godward, S., Sandhu, M., Skinner, J. & McCann, J. 2001, 'Re: Cellular telephones and cancer-a nationwide cohort study in Denmark', *J Natl Cancer Inst*, vol. 93, no. 11, p. 878.

Grayson, J. K. & Lyons, T. J. 1996, 'Cancer incidence in United States Air Force aircrew, 1975-89', *Aviation Space and Environmental Medicine*, vol. 67, no. 2, pp. 101-104.

Guberan, E., Campana, A., Faval, P., Guberan, M., Sweetnam, P. M., Tuyn, J. W. N. & Usel, M. 1994, 'Gender ratio of offspring and exposure to shortwave radiation among female physiotherapists', *Scandinavian Journal of Work, Environment and Health*, vol. 20, pp. 345-348.

Hardell, L. & Mild, K. H. 2001, 'Re: Cellular telephones and cancer-a nationwide cohort study in Denmark', *Journal of the National Cancer Institute*, vol. 93, no. 12, pp. 952-3.

Hardell, L., Näsman, Å., Påhlson, A. & Hallquist, A. 2000, 'Case-control study on radiology work, medical x-ray investigations, and use of cellular telephones as risk factors for brain tumors', *Medscape General Medicine*, vol. 2, no 3, pp. 1-11.

Hardell, L., Näsman, Å., Påhlson, A., Hallquist, A. & Mild, K. H. 1999, 'Use of cellular telephones and the risk for brain tumours: a case-control study', *International Journal of Oncology*, vol. 15, pp. 113-116.

Hayes, R. B., Brown, L. M., Pottern, L. M., Gomez, M., Kardaun, J. W. P. F., Hoover, R. N., O'Connell, K. J., Sutzman, R. E. & Javadpour, N. 1990, 'Occupation and risk for testicular cancer: a case-control study', *International Journal of Epidemiology*, vol. 19, no. 4, pp. 825-831.

Hill, A. B. 1965, 'The environment and disease: association or causation?', *Proceedings of the Royal Society of Medicine*, vol. 58, pp. 295-300.

Hocking, B. 2001, 'Re: Cellular telephones and cancer-a nationwide cohort study in Denmark', *Journal of the National Cancer Institute*, vol. 93, no. 11, pp. 877-878.

Hocking, B., Gordon, I. & Hatfield, G. E. 1999, 'Childhood leukaemia and TV towers revisited', *Australian and New Zealand Journal of Public Health*, vol. 23, no. 1, pp. 104-105.

Hocking, B., Gordon, I. R., Grain, H. L. & Hatfield, G. E. 1996, 'Cancer incidence and mortality and proximity to TV towers', *Medical Journal of Australia*, vol. 165, pp. 601-605.

Holly, E. A., Aston, D. A., Ahn, D. K. & Smith, A. H. 1996, 'Intraocular melanoma linked to occupations and chemical exposures', *Epidemiology*, vol. 7, no. 1, pp. 55-61.

Independent Expert Group on Mobile Phones 2000, *Mobile phones and health* (Sir William Stewart, Chairman), National Radiological Protection Board, Chilton, Didcot, UK.
[Refer www.iegmp.org.uk]

Inskip, P. D. 2001, 'Frequent radiation exposures and frequency-dependent effects: the eyes have it', *Epidemiology*, vol. 12, pp. 1-4.

Inskip, P. D., Tarone, R. E., Hatch, E. E., Wilcosky, T. C., Shapiro, W. R., Selker, R. G., Fine, H. A., Black, P. M., Loeffler, J. S. & Linet, M. S. 2001, 'Cellular-telephone use and brain tumors', *N Engl J Med*, vol. 344, pp. 79-86.

International Commission on Non-ionizing Radiation Protection (ICNIRP) 1998, 'Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)', *Health Physics*, vol. 74, no. 4, pp. 494-522.

Johansen, C., Boice, J. D. Jr, McLaughlin, J. K. & Olsen, J. H. 2001a, 'Cellular telephones and cancer - a nationwide cohort study in Denmark', *Journal of the National Cancer Institute*, vol. 93, no. 3, pp. 203-207.

Johansen, C., Boice, J. D. Jr, McLaughlin, J. K. & Olsen, J. H. 2001b, 'Response: Cellular telephones and cancer - a nationwide cohort study in Denmark', *Journal of the National Cancer Institute*, vol. 93, no. 11, pp. 878-879.

Johansen, C., Boice, J. D. Jr, McLaughlin, J. K. & Olsen, J. H. 2001c, 'Response: Cellular telephones and cancer - a nationwide cohort study in Denmark', *Journal of the National Cancer Institute*, vol. 93, no. 12, pp. 952-953.

Kallen, B., Malmquist, G. & Moritz, U. 1982, 'Delivery outcome among physiotherapists in Sweden: is non-ionizing radiation a fetal hazard?', *Archives of Environmental Health*, vol. 37, pp. 81-84.

Kaplan, S., Etlin, S., Novikov, I. & Modan, B. 1997, 'Occupational risks for the development of brain tumors', *American Journal of Industrial Medicine*, vol. 31, pp. 15-20.

Kolodynski, A. A. & Kolodynska, V. V. 1996, 'Motor and psychological functions of school children living in the area of the Skrunda Radio Location Station in Latvia', *Science of the Total Environment*, vol. 180, pp. 87-93.

Lagorio, S., Rossi, S., Vecchia, P., de Santis, M., Bastianini, L., Fusilli, M., Ferrucci, A., Desideri, E. & Comba, P. 1997, 'Mortality of plastic-ware workers exposed to radiofrequencies', *Bioelectromagnetics*, vol. 18, pp. 418-421.

Larsen, A. I. 1991, 'Congenital malformations and exposure to high-frequency electromagnetic radiation among Danish physiotherapists', *Scandinavian Journal of Work, Environment & Health*, vol. 17, pp. 318-323.

Larsen, A. I., Olsen, J. & Svane, O. 1991, 'Gender-specific reproductive outcome and exposure to high-frequency electromagnetic radiation among physiotherapists', *Scandinavian Journal of Work, Environment & Health*, vol. 17, pp. 324-329.

MacMahon, B. & Pugh, T. F. 1970, *Epidemiology: principles and methods*, 1st edn, Little Brown, Boston USA.

Mann, K. & Röschke, J. 1996, 'Effects of pulsed high-frequency electromagnetic fields on human sleep', *Neuropsychobiology*, vol. 33, no. 1, pp. 41-47.

McKenzie, D. R., Yin, Y. & Morrell, S. 1998, 'Childhood incidence of acute lymphoblastic leukaemia and exposure to broadcast radiation in Sydney - a second look', *Australian and New Zealand Journal of Public Health*, vol. 22, pp. 360-367.

Milham, S. 1988, 'Increased mortality in amateur radio operators due to lymphatic and hematopoietic malignancies', *American Journal of Epidemiology*, vol. 127, pp. 50-54.

Morgan, R. W., Kelsh, M. A., Zhao, K., Exuzides, K. A., Heringer, S. & Negrete, W. 2000, 'Radiofrequency exposure and mortality from cancer of the brain and lymphatic/hematopoietic systems', *Epidemiology*, vol. 11, pp. 118-127.

Muscat, J. E., Malkin, M. G., Thompson, S., Shore, R., Stellman, S., McRee, D., Neugut, A. I. & Wynder, E. L. 2000, 'Handheld cellular telephone use and risk of brain cancer', *JAMA*, vol. 284, pp. 3001-3007.

Ouellet-Hellstrom, R. & Stewart, W. F. 1993, 'Miscarriages among female physical therapists who report using radio- and microwave- frequency electromagnetic radiation', *American Journal of Epidemiology*, vol. 138, no. 10, pp. 775-786.

Park, R. L. 2001, 'Cellular telephones and cancer: how should science respond?', *Journal of the National Cancer Institute*, vol. 93, no. 3, pp. 166-167.

Reid, S. W. & Gettinby, G. 1998, 'Radio-frequency electromagnetic field from mobile phones', *Lancet*, vol. 352, no. 9127, pp. 576-577.

Robinette, C. D., Silverman, C. & Jablon, S. 1980, 'Effects upon health of occupational exposure to microwave radiation (radar)', *American Journal of Epidemiology*, vol. 112, no. 1, pp. 39-53.

Rothman, K. J., Chou, C.-K., Morgan, R., Balzano, Q., Guy, A. W., Funch, D. P., Preston-Martin, S., Mandel, J., Steffens, R. & Carlo, G. 1996b, 'Assessment of cellular telephone and other radio frequency exposure for epidemiologic research', *Epidemiology*, vol. 7, pp. 291-298.

Rothman, K. J., Loughlin, J. E., Funch, D. P. & Dreyer, N. A. 1996a, 'Overall mortality of cellular telephone customers', *Epidemiology*, vol. 7, pp. 303-305.

Royal Society of Canada 1999, *A review of the potential health risks of radiofrequency fields from wireless telecommunication devices*, The Royal Society of Canada, Ottawa Canada.

Röschke, J. & Mann, K. 1997, 'No short-term effects of digital mobile radio telephone on the awake human electroencephalogram', *Bioelectromagnetics* , vol. 18, no. 2, pp. 172-176.

Selvin, S., Schulman, J. & Merrill, D. W. 1992, 'Distance and risk measures for the analysis of spatial data: a study of childhood cancers', *Social Science and Medicine*, vol. 34, no. 7, pp. 769-777.

Stang, A., Anastassiou, G., Ahrens, W., Bromen, K., Bornfeld, N. & Jockel, K.-H. 2001, 'The possible role of radiofrequency radiation in the development of uveal melanoma', *Epidemiology*, vol. 12, pp. 7-12.

Szmigielski, S. 1996, 'Cancer morbidity in subjects occupationally exposed to high frequency (radiofrequency and microwave) electromagnetic radiation', *Science of the Total Environment*, vol. 180, pp. 9-17.

Taskinen, H., Kyyronen, P. & Hemminki, K. 1990, 'Effects of ultrasound, shortwaves, and physical exertion on pregnancy outcome in physiotherapists', *Journal of Epidemiology and Community Health*, vol. 44, pp. 196-201.

Thomas, T. L., Stolley, P. D., Stemhagen, A., Fontham, E. T. H., Bleeker, M. L., Stewart, P. A. & Hoover, R. N. 1987, 'Brain tumour mortality risk among men with electrical and electronic jobs: a case-control study', *Journal of the National Cancer Institute*, vol. 79, no. 2, pp. 233-238.

Trichopoulos, D. & Adami, H. O. 2001, 'Cellular telephones and brain tumors', *N Engl J Med*, vol. 344, no. 2, pp. 133-134.

Tynes, T., Hannevik, M., Andersen, A., Vistnes, A. I. & Haldorsen, T. 1996, 'Incidence of breast cancer in Norwegian female radio and telegraph operators', *Cancer Causes and Control*, vol. 7, pp. 197-204.

Wagner, P., Röschke, J., Mann, K., Hiller, W. & Frank, C. 1998, 'Human sleep under the influence of pulsed radiofrequency electromagnetic fields: a polysomnographic study using standardized conditions', *Bioelectromagnetics*, vol. 19, no. 3, pp. 199-202.

Annex 4

Research into RF Bio-Effects at Low Levels of Exposure

Summary

As indicated in the Rationale section, harmful effects of RF radiation have been shown to follow if sustained rises in temperature in living tissue by several °C are allowed to occur. Whilst some bio-effects may be identified at temperature rises of 1°C or less, these are not considered hazardous, but the question remains as to whether repeated doses at these levels over many months or years may lead to hazard. Current evidence is that it does not.

A further and more vexing question is whether there may exist a form of RF energy absorption that may not manifest itself in a measurable increase in tissue temperature, but could nevertheless be linked to bio-effects. These have been termed athermal or non-thermal effects, but since there is still the possibility of these being due to a local thermal mechanism, the term 'low-level effects' is preferred. These reported effects could be due to a) a differential uptake of RF energy by specific cell types or cellular components; b) non-uniformities in energy absorption patterns within an exposure system; c) a resonant absorption mechanism which is non-thermal in nature; d) experimental artefact or statistical anomaly. Whether the mechanism is actually thermal or not, or whether these reported bio-effects are real or artefactual, those effects suggesting statistically significant biological interactions at SAR levels well below 1 W/kg need to be replicated satisfactorily, particularly if they are suggestive of harm, before they can form the basis of standard setting.

The review of scientific literature and consideration of possible low-level effects in the ICNIRP Guidelines (ICNIRP 1998) was noted. Around 80 studies relevant to the question of low-level interactions were identified in published peer-reviewed journals after the ICNIRP cut-off date (1997), and these are briefly reviewed below. These papers were considered in some detail. Particular attention was paid to those papers that had a direct impact on what the basic SAR restrictions should be. In addition, the ICNIRP Guidelines did not consider human volunteer studies to low-level exposures per se; a discussion of these is also included.

Overall, it was concluded that exposures leading to SAR values below the basic restrictions given in section 2 do not lead to unambiguous biological effects indicative of adverse physiological or psychological function or to increased susceptibility to disease. Whilst these low-level effects have not been established, they cannot be ruled out and so more research is needed.

General

ICNIRP, in developing exposure limits, considered the issue of possible low-level interactions of high frequency EMF. In the ICNIRP Guidelines, scientific reports up to 1997 were considered and a general conclusion expressed as: 'In general the effects of exposure of biological systems to athermal levels of amplitude-modulated EMF are small and very difficult to relate to potential health effects' (ICNIRP 1998, p508).

The studies can be divided into those that attempt to identify any effects of low-level exposure that could lead to specific diseases, in particular, cancer, and those which study changes in physiological or psychological performance. Although changes in the latter case may not be considered pathological, they would still indicate a previously unsuspected mode of interaction and would be of concern in relation to capacity of exposed individuals to function optimally. In general, studies of the former type involve exposures over days or months, whereas the latter often involve exposures of a few hours duration.

One of the difficulties in identifying low-level effects is that of unambiguously eliminating the possibility of significant rise in temperature in localised areas in the biological system under study. Chou et al. (1999) have shown that the ratio of maximum to average SAR in the brain tissue of small mammals exposed to a mobile phone simulator is 2:1, and in the scalp this ratio is ten times the brain average. SAR distributions within cell and tissue samples in exposure systems commonly used for in-vitro experiments have been extensively studied by Guy, Chou and McDougall (1999). Ratios of maximum to average SAR values range from 3 to 15, depending on the exact configuration. Effects that may appear to be athermal based on the average SAR value, may thus be due to a localised elevation in absorption.

The World Health Organization maintains a website summarising recent work, which is complete or under way, relevant to the frequency range covered by this Standard. This can be found via www.who.int/peh-emf. This website also has details of the WHO research agenda and its on-going role in the coordination of research.

Studies examining indicators of pathological change

It should be pointed out that reviews of literature prior to 1997 have not indicated there to be any substantive evidence of deleterious changes under any of the following headings. Rather, these headings refer to areas of research which have been active for several years in relation to RF safety.

Epidemiological studies on human populations

Epidemiological studies, at the low-levels of exposure normally encountered in the workplace or general environment, are reviewed in Annex 3.

Cancer incidence in animals

In relation to long-term exposure of laboratory animals to microwave radiation, the ICNIRP Guidelines (ICNIRP 1998) cite the experiment of Repacholi et al. (1997) as suggestive of a non-thermal mechanism acting to produce an excess of lymphoma in genetically engineered mice. However, in none of the studies published subsequently has there been any evidence of increased incidence of cancer-related end-points. These studies have included the effects of mobile phone-type RF radiation both on spontaneous tumours (Adey et al. 1999; Frei et al. 1998a, 1998b; Toler et al. 1997) and those induced by chemical compounds (Adey et al. 1999; Chagnaud, Moreau & Veyret 1999; Imaida et al. 1998a, 1998b), ionizing radiation (Juutilainen et al. in press) or injection of cancerous cells (Higashikubo et al. 1999). In fact, Adey et al. (1999) show a significant protective effect of RF radiation in one sub-group of animals.

Animal fertility

Two studies have suggested reduced fertility in rats at environmental levels of RF (Magras & Xenos 1997: VHF, UHF bands) and at occupational levels (Brown-Woodman et al. 1989: 27 MHz band). However, because of the experimental design, these should be regarded as pilot studies. A recent review by Jensh (1997), covering experiments in the microwave bands, concluded that these exposures 'do not induce a consistent, significant increase in reproductive risk as assessed by classical morphologic and postnatal psychophysiologic parameters'.

Immune system function

Elekes, Thyuroczy & Szabo (1996) found increases due to amplitude modulated (AM) microwave radiation, with an estimated SAR of 0.14 W/kg, in antibody-producing cells in mouse spleen, but this finding was restricted to male mice only. Similarly, Fesenko et al. (1999) and Novoselova et al. (1999) report significant increases in Tumor Necrosis Factor (an indicator of immune response) in mice exposed to very low SAR of modulated microwave radiation. These authors regard RF radiation as a therapeutic agent in cases of immuno-deficiency. Recent reviews, for example Jauchem (1998), have concluded that effects on immune system function have been inconsistent.

Key enzyme levels

Ornithine Decarboxylase (ODC), involved in the production of polyamines, which in turn lead to cell proliferation, has been regarded as a key enzyme to study as an indicator of carcinogenesis. The outcome of RF studies has been mixed. It should be pointed out that although some carcinogenic agents elevate ODC levels, many other agents (such as heat) do so as well. Litovitz et al. (1997) and Penafiel et al. (1997) showed a two-fold enhancement in ODC activity due to AM microwaves modulated with sinusoids in the ELF range. They further showed that if ELF white noise was added to the modulation, the degree of enhancement was attenuated. Since the SAR was of the order of 2.5 W/kg, a thermal mechanism cannot be ruled out, but the attenuation due to white noise remains enigmatic. Recent replication attempts of the EMF studies of Litovitz involving extensive collaboration with the original investigator have failed (Cress, Owen & Desta 1999). The question of ODC changes in relation to ELF-modulated RF has been extensively discussed in the Royal Society of Canada Expert Panel Report (Royal Society of Canada 1999). This stresses the importance of understanding any putative non-thermal mechanism before making an assessment of possible health detriment at non-thermal levels of exposure.

Gene expression

Changes in gene expression have been reported by de Pomerai et al. (2000) and Danniells et al. (1998) in a study on transgenic nematodes using a non-thermal exposure (estimated by the authors at 1 mW/kg) of several hours. The particular gene studied induces a specific heat shock protein, normally associated with thermal stress but also induced by general adverse conditions. In contrast, Morrissey et al. (1999) and Fritze et al. (1997a) have shown that in rats altered gene expression is only associated with thermal levels of acute exposure. In these studies, expression of a gene (*c-fos*) associated with thermoregulatory and other types of stress was studied. In the case of Morrissey et al. this was increased for brain averaged SAR values of 4 W/kg or more, but in the case of Fritze et al., the changes in *c-fos* expression were attributed to the animals being restrained, rather than to the exposure condition. On the other hand, in the latter study, heat shock protein messenger RNA was increased significantly for brain SAR value or

7.5 W/kg. In isolated cell systems, Ivaschuck et al. (1997) showed no changes in c-fos expression at a number of rather low SAR values (up to 26 mW/kg), whereas Goswami et al. (1997) and Goswami et al. (1999) showed that, in general, gene transcription rates were unaffected by 0.6 W/kg analog or digital phone-type radiations. However, small but significant rises in *c-fos* were observed for certain stages in the cell cycle. Recently, Romano-Spica et al. (2000) have published evidence of in increase in oncogene induction by 50 MHz RF with 16 Hz AM and an incident power flux density of 10 W/m^2, which could be marginally thermal (Guy, Chou & McDougall 1999). Similarly, unmodulated (continuous wave) microwave radiation, has been reported to alter the production of a proto-oncogene and other factors in a human mast-cell line at an SAR of 7 W/kg (Harvey & French 2000). In summary, there is increasing evidence that gene expression can be altered at SARs which lead to overall temperature rises of less than 1°C, but there is no persuasive evidence of non-thermal mechanisms operating. The effect of temperature on biological rate processes can be characterised by the so-called Q_{10}, which measures the ratio of reaction rates for two temperatures 10^0C apart. Most biological reaction have Q_{10} values of between 2 and 3, but some membrane-associated processes have values as high as 10. The increases in rate of gene expression at SAR values of a few W/kg are consistent with a local rise in temperature of 1°C or more, particularly in view of the uncertainties in dosimetry referred to above.

Possible DNA damage

Most of the recent studies report a negative outcome with regard to effects of RF radiation on the rate of DNA strand breaks (Malyapa et al. 1997a, 1997b, 1998) for both in-vivo and in-vitro exposures. This is in contrast to earlier positive findings of Lai and Singh (reviewed in Independent Expert Group on Mobile Phones [IEGMP] 2000) and further work from this group implicating protective effects of melatonin and opioid antagonists against this damage (Lai & Singh 1997; Lai, Carino & Singh 1997). Phillips et al. (1998) report conflicting outcomes in relation to DNA damage, highlighting the simultaneous processes of putative damage and repair.

Cell proliferation rate

Tumour cell progression rate in response to digital mobile phone-type radiation was studied by Cain, Thomas and Adey (1997), revealing no significant changes.

Cell structural changes

Changes in cell characteristics have also been reported by Donnellan, McKenzie and French (1997) and French, Donnellan and McKenzie (1997), but at levels that are probably several W/kg (Rowley & Anderson 1998). Garaj-Vrhovac (1999) has recently reported increased incidence of micronucleus formation in lymphocytes of occupationally exposed individuals. Vijayalaxmi et al. (1997) found increased incidence of micronucleus formation in blood and marrow cells in tumor-prone mice. In this case the RF radiation was 2.45 GHz with a SAR of 1 W/kg. Asanami and Shimono (1997) have shown micronucleus formation increases from 2°C increases in core body temperature, which are possible at this SAR value.

Blood-brain barrier permeability

Experiments have been carried out to determine whether RF energy has any effects on the blood-brain barrier (BBB) since the 1970s. Results of these experiments have been inconsistent. Recently, Persson, Salford and Brun (1997)

have reported significant increase in leakage of albumin and fibrinogen across the BBB of rats exposed in vivo to mobile phone type radiation, with a threshold specific absorption energy of 1.5 J/kg. Since this amount of energy absorption would be achieved by a SAR of 4 W/kg in less than a second, some independent verification of actual SAR values is called for. Tsurita et al. (2000), using Evans Blue as a marker for BBB permeability, failed to demonstrate any changes in relation to 1.44 GHz TDMA radiation with brain SARs of up to 2 W/kg. On the other hand, using a co-culture of astrocytes and endothelial cells in an in vitro model of the BBB, Schirmacher et al. (2000), showed an approximate doubling of permeability to sucrose after 4 days of exposure to GSM-modulated 1.8 GHz radiation at an estimated SAR of 0.3 W/kg. Infra red thermometry of the culture samples was used to verify that the temperature changes were insignificant. Fritze et al. (1997b), studying BBB permeability to albumin in rats exposed to 900 MHz GSM radiation in vivo for a period of over several days, found significant changes only at the highest SAR, 7.5 W/kg.

Studies of markers of physiological or psychological performance

Studies of this type have concentrated entirely on mobile phone frequencies, but previous reviews (see, for example, Royal Society of Canada 1999) have covered the spectrum range 3 kHz - 300 GHz without identifying any clear evidence of non-thermal mechanisms affecting physiological or psychological performance.

Calcium levels within cells

ICNIRP (1998) discussed the status of experiments in which calcium efflux from tissue or levels in cells had been studied in relation to low intensity modulated RF exposure. Levels of calcium in guinea pig myocytes and other cells in response to GSM phone-type radiation has been studied by Wolke et al. (1996), without indicating any effect.

Melatonin and other hormone levels

The output of the hormone melatonin from the pineal gland, which has been reported to be altered by changes in the earth's magnetic field and possibly by 50/60Hz fields, has been studied in humans exposed to mobile phone radiation by de Seze et al. (1999), and Mann et al. (1998a), without any significant changes being identified. Similar lack of effect was found by Vollrath et al. (1997) in hamsters. Stark et al. (1997), although finding no chronic effects, noted a significant increase in melatonin output in dairy cows on the night following resumption of exposure (to radio transmission tower radiation) after 3 days of non-exposure. Output of a range of hormones from the anterior pituitary was also studied by de Seze, Fabbro-Peray & Miro (1998), without showing any long-lasting or cumulative effects. Mann et al. (1998a) examined nocturnal profiles of growth hormone, luteinising hormone and serum cortisol, in addition to melatonin, discussed above. A transient increase in cortisol levels, well within the normal range of variation, immediately after onset of exposure was noted. This could indicate an adaptation to possible thermal loading.

Blood pressure and heart rate

Braune et al. (1998a, 1998b) noted significant increases in blood pressure of between 5 and 10 mm Hg for human subjects exposed to mobile phone radiation to the right side of the head, but in an experiment in which there was a fixed sequence of exposure and non-exposure conditions, thus not eliminating changes

due to the elapsing of time. Lu et al. (1999) have shown a decrease in blood pressure in rats exposed to two types of Ultra-wideband pulses (UWB), with SAR values of 0.07 and 0.121 W/kg. Jauchem et al. (1998, 1999) could not identify any changes in heart rate and blood pressure of rats exposed to UWB. Szmigielski et al. (1998) reported attenuated amplitudes and shifts in diurnal rhythms of blood pressure and heart rate in volunteers occupationally exposed to 740 - 1500 kHz broadcast transmitters. On the other hand, Mann et al. (1998b) report no changes in heart rate variability in volunteers exposed to mobile phone-type radiation during sleep. Inconsistency of outcomes thus makes it difficult to assess possible health implications.

Brain electrical activity

Brain electrical activity (EEG) has been monitored both during sleep and to more immediate responses to visual, auditory or cognitive stimuli. Borbély et al. (1999) and Huber et al. (2000) noted increases in EEG spectra in the 7 – 14 Hz band associated with mobile phone type EME exposure during sleep, during the first few hours of sleep, but Röschke and Mann (1997), Wagner et al. (1998), and Mann and Röschke (1996) could not identify consistent changes in these parameters. A significant decrease in wake time after sleep was noted by Borbély et al. (1999) and a non-significant change in the same direction by Wagner et al. (1998) and Huber et al. (2000). These reported changes are within the range of variation observed day-to-day or between individuals.

In regard to immediate changes in brain activity, Urban, Lukas and Roth (1998) showed no changes associated with visual stimuli, but Eulitz et al. (1998) found significant alterations in high frequency spectral content of responses to an auditory task. Freude et al. (1998, 2000) showed significant changes in electrical activity in the preparatory phase of a complex visual monitoring task, in two separate series of experiments. Similarly Krause et al. (2000) showed increase in the 8-10 Hz band in a memory search task. Kellenyi et al. (1999) report altered auditory brainstem response in volunteers exposed for 15 minutes to GSM phone-type radiation and concomitant hearing deficiency. Without a detailed knowledge of the type of test signal applied (for example, whether the earpiece was muted) it is impossible to comment on this result. Vorobyov et al. (1997) report inconsistent changes in EEG hemispherical asymmetry in rats exposed to ELF modulated 945 MHz RF radiation of up to 2 W/m^2.

Neuropsychological tests

In a battery of tests, significant shortening in reaction time has been reported in two separate studies (Preece et al. 1999; Koivisto et al. 2000a). However, there is some inconsistency in that the specific test that showed significant shortening in the first did show significant changes in the second, and vice versa. The study of Preece et al. (1999) also showed significant changes only for analog mobile phones and not for digital, whereas Koivisto et al. (2000a) studied only digital phones. Hladky et al. (1999) found no significant changes in attention and memory tasks following short (6 min.) exposures to mobile phone radiation. However, a recent study of Koivisto et al. (2000b) has revealed a significant improvement in a working memory task. On the other hand, in an experiment involving rats exposed to 2.45 GHz radiation in a water maze, Wang and Lai (2000) reported a deficit in spatial memory.

Other issues relating to mechanism of interaction of RF with biological systems

There are numerous reports of thermal levels of RF being used in humans. For example, short-wave diathermy or microwave applicators being used to alleviate muscle and joint pain and as an adjunct to radiotherapy or chemotherapy. The study of Detlavs et al. (1996) is unusual in that it claims improvement in the rate of healing of soft tissue injury at non-thermal levels of modulated microwaves in the 40–55 GHz band. These experiments require independent replication before it can be accepted that there truly is a non-thermal mechanism operating.

The effect of RF exposure on thresholds to other agents: Verschaeve and Maes (1998) have reviewed evidence of possible synergistic effects between RF exposure and exposure to toxic chemicals or other agents. The question of the effect of concurrent thermal levels of RF exposure on the toxicity of industrial solvent has been studied by Nelson et al. (1997a, 1997b, 1998) and Nelson, Snyder and Shaw (1999), but there is no question here that a non-thermal mechanism may be acting.

Isothermal exposure (that is, exposure to levels of RF that would cause an appreciable rise in temperature, but in which the temperature of the experimental system is deliberately kept at a fixed value) has been studied by Cleary for a number of years (see Cleary et al. 1997, for example). A number of anomalous results point to a possible non-thermal mechanism operating. However, significant non-uniform temperature distributions within exposed cell cultures cannot be ruled out, particularly with the very high SARs used in the experiments.

Unanswered Questions

There are a number of issues that still need to be clarified in terms of their possible implications for health and welfare. Although the overwhelming majority of studies in experimental animals have failed to show a link between RF exposure and cancer, the repeat of the study by Repacholi et al. (1997) showing an excess lymphoma rate in genetically engineered mice, (referred to as the 'Adelaide Study') is awaited with interest.

Alterations in blood-brain barrier permeability could lead to inappropriate exposure of neural tissue to blood-borne pathogens, thus it is important to discover whether this alteration is a consequence of tissue heating at SAR levels above the basic restrictions. Similarly, changes in gene expression may also be a consequence of thermal effects, but it is important to continue to refine methods for determining local SAR and to evaluate whether any changes have any serious health implications.

Neuropsychological and neurophysiological testing may suggest that altered human responsiveness may result from RF levels just below the basic restrictions, but it remains to be unambiguously demonstrated that this is the case, and that any alterations would have serious implications in terms of well-being.

In summary, it would appear that although non-thermal effects or mechanisms cannot be ruled out, the evidence for them is inconsistent and further confirmatory studies need to be carried out, particularly in relation to SAR estimations.

References

Adey, W. R., Byus, C. V., Cain, C. D., Higgins, R. J., Jones, R. A., Kean, C. J., Kuster, N., MacMurray, A., Stagg, R. B., Zimmerman, G., Phillips, J. L. & Haggren, W. 1999, 'Spontaneous and nitrosourea-induced primary tumours in Fischer 344 rats chronically exposed to 836 MHz modulated microwaves', *Radiation Re*search, vol. 152, p. 293.

Asanami, S. & Shimono, K. 1997, 'High body temperature induces micronuclei in mouse bone marrow', *Mutation Research,* vol. 390, pp. 79-83.

Borbély, A. A., Huber, R., Graf, T., Fuchs, B., Gallmann, E. & Achermann, P. 1999, 'Pulsed high-frequency electromagnetic field affects human sleep and sleep electroencephalogram', *Neuroscience Letters*, vol. 275, p. 207.

Braune, S., Wrocklage, C., Raczek, J., Gailus, T. & Lucking, C. H. 1998a, 'Resting blood pressure increase during exposure to a radiofrequency electromagnetic field', *Lance*t, vol. 351, p. 1857.

Braune, S., Wrocklage, C., Raczek, J., Gailus, T. & Lucking, C. H. 1998b, 'Radiofrequency electromagnetic field from mobile phones', *Lance*t, vol. 352, p. 576.

Brown-Woodman, P. D., Hadley, J. A., Richardson, L., Bright, D. & Porter, D. 1989, 'Evaluation of reproductive function of female rats exposed to radiofrequency fields (27.12 MHz) near a shortwave diathermy device', *Health Physics,* vol. 56, pp. 521-525.

Cain, C. D., Thomas, D. L. & Adey, W. R. 1997, 'Focus formation of C3H/10T1/2 cells and exposure to a 836.55 MHz modulated radiofrequency field', *Bioelectromagnetic*s, vol. 18, p. 237.

Chagnaud, J. L., Moreau, J. M. & Veyret B. 1999, 'No effect of short-term exposure to GSM-modulated low-power microwaves on benzo(á)pyrene-induced tumours in rat' *International Journal of Radiation Biology,* vol. 75(10), p. 1251.

Chou, C. K, Chan, K.W., McDougall, J. A. & Guy, A. W. 1999, 'Development of rat head exposure system for simulating human exposure to RF fields from wireless telephone telephones' *Bioelectromagnetics* , vol. 20, Suppl 4, pp. 75-92.

Cleary, S. F., Cao, G., Liu, L. M., Egle, P. M. & Shelton, K. R. 1997, 'Stress proteins are not induced in mammalian cells exposed to radiofrequency or microwave radiation', *Bioelectromagnetics,* vol. 18, pp. 499-505.

Cress, L. W., Owen, R. D. & Desta, A. B. 1999, 'Ornithine decarboxylase activity in L929 cells following exposure to 60 Hz fields', *Carcinogenesis*, 20, 1025-1030.

Danniells, C., Duce, I., Thomas, D., Sewell, P., Tattersall, J. & de Pomerai, D. 1998, 'Transgenic nematodes as biomonitors of microwave-induced stress', *Mutation Research,* vol. 399, p. 55.

de Pomerai, D., Daniells, C., David, H., Allan, J., Duce, I., Mutwaki, M., Thomas, D., Sewell, P., Tattersall, D., Jones, D. & Candido, P. 2000, 'Non-thermal heat-shock response to microwaves', *Nature*, vol. 405, pp. 417-418

de Seze, R., Ayoub, J., Peray, P., Miro, L. & Touitou, Y. 1999, 'Evaluation in humans of the effects of radiocellular telephones on the circadian patterns of melatonin secretion, a chronobiological rhythm marker', *Journal of Pineal Research,* vol. 27, pp. 237-242.

de Seze, R., Fabbro-Peray, P. & Miro, L. 1998, 'GSM radiocellular telephones do not disturb the secretion of antepiuitary hormones in humans', *Bioelectromagnetics,* vol. 19, pp. 271-278.

Detlavs, I., Dombrovska, L., Turauska, A., Shkirmante, B. & Slutskii, L. 1996, 'Experimental study of the effects of radiofrequency electromagnetic fields on animals with soft tissue wounds', *Science of the Total Environment,* vol. 180, pp. 35-42.

Donnellan, M., McKenzie, D. R. & French, P. W. 1997, 'Effects of exposure to electromagnetic radiation at 835 MHz on growth, morphology and secretory characteristics of a mast cell analogue', *Cell Biology International,* vol. 21, pp. 427-439.

Elekes, E., Thuroczy, G. & Szabo, L. D. 1996, 'Effect on the immune system of mice exposed chronically to 50 Hz amplitude-modulated 2.45 GHz microwaves', *Bioelectromagnetics,* vol. 17, pp. 246-248.

Eulitz, C., Ullsperger, P., Freude, G. & Elbert, T. 1998, 'Mobile phones modulate response patterns of human brain activity', *NeuroReport,* vol. 9, p. 3229.

Fesenko, E. E., Makar V. R., Novoselova E. G. & Sadovnikov V. B. 1999,' Microwaves and cellular immunity. I. Effect of whole body microwave irradiation on tumor necrosis factor production in mouse cells', *Bioelectrochemistry and Bioenergetics,* vol. 49, pp. 29-35.

Frei, M.R., Berger, R.E., Dusch, S.J., Guel, V., Jauchem, J.R., Merritt, J.H. & Stedham, M.A. 1998a, 'Chronic exposure of cancer-prone mice to low-level 2450 MHz radiofrequency radiation', *Bioelectromagnetic*s, vol. 19, p. 20.

Frei, M. R., Jauchem, J. R., Dusch, S. J., Merritt, J. H., Berger, R. E. & Stedham, M. A. 1998b, 'Chronic, low-level (1.0 W/kg) exposure of mice prone to mammary cancer to 2450 MHz microwaves', *Radiation Research,* vol. 150, p. 568.

French, P. W., Donnellan M. & McKenzie D. R. 1997 'Electromagnetic radiation at 835 MHz changes the morphology and inhibits proliferation of a human astrocytoma cell line', *Bioenergetics,* vol. 43, pp. 13-18.

Freude, G., Ullsperger, P., Eggert, S. & Ruppe, I. 1998, 'Effects of microwaves emitted by cellular phones on human slow brain potentials', *Bioelectromagnetic*s, vol. 19, p. 384.

Freude, G., Ullsperger, P., Eggert, S. & Ruppe, I. 2000, 'Microwaves emitted by cellular telephones affect human slow brain potentials', *European Journal of Applied Physiology,* vol. 81, pp. 18-27.

Fritze, K., Wiessner, C. Kuster, N., Sommer, C., Gass, P., Hermann, D. M., Kiessling, M. & Hossmann, K. A. 1997a, 'Effect of Global system for mobile communication microwave exposure on the genomic response of the rat brain', *Neuroscience,* vol. 81(3), p. 627.

Fritze, K., Sommer, C., Schmitz, B., Mies G., Hossmann K. A., Kiessling M. & Wiessner C. 1997b 'Effect of Global system for mobile communication (GSM) microwave exposure on blood-brain barrier permeability in rat', *Acta Neuropathologica*, vol. 94, pp. 465-470.

Garaj-Vrhovac, V. 1999, 'Micronucleus assay and lymphocyte mitotic activity in risk assessment of occupational exposure to microwave radiation', *Chemosphere,* vol. 39, pp. 2301-2312.

Goswami, P. C., Albee, L. D., Spitz, D. R. & Ridnour, L. A. 1997, 'A polymerase chain reaction assay for simultaneous detection and quantitation of proto-oncogene and GAPD mRNAs', *Cell Proliferation,* vol. 30, pp. 271-282.

Goswami, P. C., Albee, L. D., Parsian, A. J., Baty, J. D., Moros, E. G., Pickard, W. F., Roti-Roti, J. L. & Hunt, C. R. 1999, 'Expression of proto-oncogene and activities of multiple transcription factors in RF exposed cells, using C3H10T1/2 mouse embryo fibroblast cells exposed to 835.62 and 847.74 MHz cellphone radiations', *Radiation Research,* vol. 151*,* no. 3, pp. 300-309.

Guy, A. W., Chou, C. K. & McDougall, J. A. 1999, 'A quarter century of in vitro research: a new look at exposure methods', *Bioelectromagnetics,* vol. 20, Suppl 4, pp. 21-39.

Harvey, C. & French, P. W. 2000. 'Effects on protein kinase C and gene expression in a human mast cell line, HMC-1, following microwave exposure', *Cell Biol International,* vol. 23*,* pp. 739-748.

Higashikubo, R., Culbreath, V. O., Spitz, D. R., LaRegina, M. C., Pickard, W. F., Straube, W. L., Moros, E. G. & Roti Roti, J. L. 1999, 'Radiofrequency electromagnetic fields have no effect on the *in vivo* proliferation of the 9L brain tumour', *Radiation Research*, vol. 152, p. 665.

Hladky, A., Musil, J., Roth, Z., Urban, P. & Blazkova, V. 1999, 'Acute effects of using a mobile phone on CNS functions', *Central European Journal of Public Health,* vol. 7, pp. 165-167.

Huber, R., Graf, T., Cote, K.A., Wittmann, L., Gallmann, E., Matter, D., Schuderer, J., Kuster, N., Borbely, A.A. & Achermann, P. 2000, 'Exposure to pulsed high-frequency electromagnetic field during waking affects human sleep EEG', *Neuroreport*, vol. 11, no. 15, pp. 3321-3325.

ICNIRP 1998, 'Guidelines for limiting exposure to time varying electric, magnetic, and electromagnetic fields (up to 300 GHz)', *Health Physics,* vol. 74, pp. 494-522.

Imaida, K., Taki, M., Watanabe, S., Kamimura, Y., Ito, T., Yamaguchi, T., Ito, N. & Shirai, T. 1998b, 'The 1.5 GHz electromagnetic near-field used for cellular phones does not promote rat liver carcinogenesis in a medium-term liver bioassay', *Japanese Journal of Cancer Research*, vol. 89, p. 995.

Imaida, K., Taki, M., Yamaguchi, T., Ito, T., Watanabe, S., Wake, K., Aimoto, A., Kamimura, Y., Ito, N. & Shirai, T. 1998a, 'Lack of promoting effects of the electromagnetic near-field used for cellular phones (929.2 MHz) on rat liver carcinogenesis in a medium-term liver bioassay', *Carcinogenesis*, vol. 19, p. 311.

Independent Expert Group on Mobile Phones 2000, *Mobile phones and health* (Sir William Stewart, Chairman), National Radiological Protection Board, Chilton, Didcot, UK.
[Refer www.iegmp.org.uk]

Ivaschuck, O. I., Jones, R. A., Ishida-Jones, T., Haggren, W., Adey, W. R. & Phillips, J. I. 1997, 'Exposure of nerve growth factor-treated PC-12 rat pheochromocytoma cells to a modulated radiofrequency field at 836.55 MHz: effects on c-jun and c-fos expression', *Bioelectromagnetics*, vol. 18, p. 223.

Jauchem, J. R. 1998, 'Health effects of microwave exposures: a review of recent (1995-1998) literature', *Journal of Microwave Power and Electromagnetic Energy,* vol. 33, p. 263.

Jauchem, J. R., Seaman, R. L., Lehnert, H. M., Mathur, S. P, Ryan, K. L., Frei, M. R. & Hurt, W. D. 1998, 'Ultra-wideband electromagnetic pulses: lack of effects on heart rate and blood pressure during two-minute exposures of rats', *Bioelectromagnetics,* vol. 19, pp. 330-333.

Jauchem, J. R., Frei, M. R., Ryan, K. L., Merritt, J. H. & Murphy, M. R. 1999, 'Lack of effects on heart rate and blood pressure in ketamine-anesthetised rats briefly exposed to ultra-wideband electromagnetic pulses', *IEEE Transcripts of Biomedical Engineering*, vol. 46, pp. 117-120.

Jensh, R. P. 1997, 'Behavioral teratologic studies using microwave radiation: is there an increased risk from exposure to cellular phones and microwave ovens?', *Reproductive Toxicology,* vol. 11, pp. 601-11.

Juutilainen, J., Heikinnen, P., Kosma, V. M., Hongisto, T., Huuskonen, H., Hyysalo, P., Komulainen, H., Kumlin, T., Lahtinen, T., Land, S., Penttila, I., Puranen, L. & Väänänen, A. (in press), 'Do pulse-modulated or continuous 900 MHz RF fields enhance the carcinogenic effect of ionising radiation in mice?', *Proceedings 1st International Medical Scientific Congress 'Non-Ionizing High-frequency EM Radiations: Researching the Epidemiology and Clinical Evidence*', Rome Italy.

Kellenyi, L., Thuroczy, G., Faludy, B, & Lenard, L 1999, 'Effects of mobile GSM radiotelephone exposure on the auditory brainstem response (ABR)', *Neurobiology,* vol. 7, pp. 79-81.

Koivisto, M., Revonsuo, A., Krause, C., Haarala, C., Sillanmaki, L., Laine, M. & Hamalainen, H. 2000a, 'Effects of 902 MHz electromagnetic field emitted by cellular telephones on response times in humans', *NeuroReport* , vol. 11, pp. 13-415.

Koivisto, M., Krause C., Revonsuo, A., Laine, M. & Hamalainen, H. 2000b, 'The effects of electromagnetic field emitted by GSM phones on working memory', *NeuroReport*, vol. 11, pp. 1641-1643.

Krause, C. M., Sillanmaki, L., Koivisto, M., Haggqvist, A., Saarela, C., Revonsuo, A., Laine, M. & Hamalainen, H. 2000, 'Effects of electromagnetic field emitted by cellular phones on the EEG during a memory task', *NeuroReport,* vol.11, pp. 761-764.

Lai, H., Carino, M. A. & Singh, N. P. 1997, 'Naltrexone blocks RFR-induced DNA double strand breaks in rat brain cells', *Wireless Networks,* vol. 3, 471-476.

Lai, H. & Singh, N. P. 1997, 'Melatonin and a spin-trap compound block radiofrequency electromagnetic radiation-induced DNA strand breaks in rat brain cells', *Bioelectromagnetics,* vol. 18, pp. 446-454.

Litovitz, T. A., Penafiel, L. M., Farrel, J. M., Krause, D., Meister, R. & Mullins, J. M. 1997, 'Bioeffects induced by exposure to microwaves are mitigated by superposition of ELF noise', *Bioelectromagnetics,* vol. 18, pp. 422-430.

Lu, S. T., Mathur, S. P., Akyel, Y. & Lee, J. C. 1999, 'Ultrawide-band electromagnetic pulses induced hypotension in rats', *Physiology and Behavior,* vol. 67, pp. 753-761.

Magras, I. N. & Xenos, T. D. 1997, 'RF radiation-induced changes in the prenatal development of mice', *Bioelectromagnetics,* vol. 18, pp. 455-461.

Malyapa, R. S., Ahern, E. W., Bi, C., Straube, W. L., LaRegina, M., Pickard, W. F. & Roti Roti, J. L. 1998, 'DNA damage in rat brain cells after *in vivo* exposure to 2450 MHz electromagnetic radiation and various methods of euthanasia', *Radiation Research*, vol. 149, p. 637.

Malyapa, R. S., Ahern, E. W., Straube, W. L., Moros, E. G., Pickard, W. F. & Roti Roti, J. L. 1997a, 'Measurement of DNA damage following exposure to 2450 MHz electromagnetic radiation', *Radiation Research*, vol. 148, p. 608.

Malyapa, R. S., Ahern, E. W., Straube, W. L., Moros, E. G., Pickard, W. F. & Roti Roti, J. L. 1997b, 'Measurement of DNA damage following exposure to electromagnetic radiation in the cellular communications frequency band (835.62 and 847.74 MHz)', *Radiation Research*, vol. 148, p. 618.

Mann, K. & Röschke, J. 1996, 'Effects of pulsed high-frequency electromagnetic fields on human sleep', *Neuropsychobiology,* vol. 33, p. 41.

Mann K., Wagner P., Brunn G., Hassan F., Hiemke C. & Röschke J. 1998a, 'Effects of pulsed high-frequency electromagnetic fields on the neuroendocrine system', *Neuroendocrinology*, vol 3, no. 2, pp. 139-144.

Mann, K., Röschke, J., Connemann, B. & Beta, H. 1998b, 'No effects of pulsed high-frequency electromagnetic fields on heart rate variability during human sleep', *Neuropsychobiology*, vol. 38, pp. 251-256.

Morrissey, J. J, Raney, S., Heasley, E., Rathinavelu, P., Dauphnee, M. & Fallon, J. H. 1999, 'Iridium exposure increases c-*fos* expression in the mouse brain only at levels which likely result in tissue heating', *Neuroscienc*e, vol. 92, p. 1539.

Nelson, B. K., Conover, D. L., Krieg, E. F. Jr, Snyder, D. L. & Edwards, R. M. 1997a, 'Interactions of RF radiation-induced hyperthermia and 2-methoxyethanol teratogenicity in rats', *Bioelectromagnetics,* vol. 18, pp. 349-359.

Nelson, B. K., Conover, D. L., Krieg, E. F. Jr, Snyder, D. L. & Edwards, R. M. 1998, 'Effect of environmental temperature on the interactive developmental toxicity of radiofrequency radiation and 2-methoxyethanol in rats', *International Archives of Occupational and Environmental Health,* vol. 71, pp. 413-23.

Nelson, B. K., Conover, D. L., Shaw, P. B., Snyder, D. L. & Edwards, R. M. 1997b, 'Interactions of radiofrequency radiation on 2-methoxyethanol teratogenicity in rats', *Journal Applied Toxicology,* vol. 17, pp. 31-39.

Nelson, B. K., Snyder, D. L. & Shaw, P. B. 1999, 'Developmental toxicity interactions of salicylic acid and radiofrequency radiation or 2-methoxyethanol in rats', *Reproductive Toxicology,* vol. 13, pp. 137-145.

Novoselova, E. G., Fesenko, E. E., Makar, V. R. & Sadovnikov, V. B. 1999, 'Microwaves and cellular immunity. II. Immunostimulating effects of microwaves and naturally occurring antioxidant nutrients', *Bioelectrochemistry and Bioenergetics,* vol. 49, pp. 37-41.

Penafiel, L. M., Litovitz, T., Krause, D., Desta, A. & Mullins, J. M. 1997, 'Role of modulation on the effect of microwaves on ornithine decarboxylase activity in L929 cells', *Bioelectromagnetics,* vol. 18, pp. 132-141.

Persson, B. R. R., Salford, L. G. & Brun, A. 1997, 'Blood-brain barrier permeability in rats exposed to electromagnetic fields used in wireless communication', *Wireless Network,* vol. 3, pp. 455-461.

Phillips, J. L., Ivaschuk, O., Ishida-Jones, T., Jones, R. A., Campbell-Beachler, M. & Haggren, W. 1998, 'DNA damage in Molt-4 T-lymphoblastoid cells exposed to cellular telephone radiofrequency fields *in vitro*', *Bioelectrochemistry and Bioenergetics*, vol. 45, pp. 103-110.

Preece, A. W., Iwi, G., Davies-Smith, A., Wesnes, K., Butler, S., Lim, E. & Varey, A. 1999, 'Effect of a 915-MHz simulated mobile phone signal on cognitive function in man', *Int J Radiation Biology*, vol. 75, p. 447.

Repacholi, M. H., Basten, A., Gebski, V., Noonan, D., Finnie, J. & Harris, A. W. 1997, 'Lymphomas in Eμ-Pim1 transgenic mice exposed to 900 MHz electromagnetic fields', *Radiation Res*, vol. 147, pp. 631-640.

Romano-Spica, V., Mucci, N., Ursini, C. L., Ianni, A. & Bhat, N. K. 2000, 'Ets1 oncogene induction by ELF-modulated 50 MHz radiofrequency electromagnetic field', *Bioelectromagnetics,* vol. 21, pp. 8-18.

Röschke, J. & Mann, K. 1997, 'No short-term effects of digital mobile radio telephone on the awake human electroencephalogram', *Bioelectromagnetics,* vol. 18, pp. 172-176.

Rowley, J. & Anderson, V. 1998, 'A critical review of resonant cavities for experimental in vitro exposure to radiofrequency fields'*, Proceedings of the Inaugural Conference of the IEEE EMBS (Vic)*, Melbourne Australia, p. 150-153.

Royal Society of Canada 1999, *A review of the potential health risks of radiofrequency fields from wireless telecommunication devices*, The Royal Society of Canada, Ottawa Canada.

Schirmacher, A., Winters, S., Fischer, S., Goeke, J., Galla, H. J., Kullnick, U., Ringelstein, E. B. & Stoegbauer, F. 2000, 'Electromagnetic fields (1.8 GHz) increase the permeability to sucrose of the blood-brain barrier in vitro', *Bioelectromagnetics,* vol. 21, pp. 338-345.

Stark, K. D., Krebs, T., Altpeter, E., Manz, B., Griot, C. & Abelin, T. 1997, 'Absence of chronic effect of exposure to short-wave radio broadcast signal on salivary melatonin concentrations in dairy cattle', *Journal Pineal Research,* vol. 22, pp. 171-176.

Szmigielski, S., Bortkiewicz, A., Gadzicka, E., Zmyslony, M. & Kubacki, R. 1998, 'Alteration of diurnal rhythms of blood pressure and heart rate to workers exposed to radiofrequency electromagnetic fields', *Blood Pressure Monitoring,* vol. 3, pp. 323-330.

Toler, J. C., Shelton, W. W., Frei, M. R, Merritt, J. H. & Stedham, M. A. 1997, 'Long-term, low-level exposure of mice prone to mammary tumours to 435 MHz radiofrequency radiation', *Radiation Research*, vol. 148, p. 227.

Urban, P., Lukas, E. & Roth, Z. 1998, 'Does acute exposure to the electromagnetic field emitted by a mobile phone influence visual evoked responses?', *Central European Journal of Public Health,* vol. 6, pp. 288-290.
Verschaeve, L. & Maes, A. 1998, 'Genetic, carcinogenic and teratogenic effects of radiofrequency fields', *Mutation Research*, vol. 410, p. 141.
Vijayalaxmi, Frei, M. R., Dusch, S. J., Guel, V., Meltz, M. L. & Jauchem, J. R. 1997, 'Frequency of micronuclei in the peripheral blood and bone marrow of cancer-prone mice chronically exposed to 2450 MHz radiofrequency radiation', *Radiation Research,* vol. 147, pp. 495-500.
Vollrath, L. R., Spessert, R. T., Kratzsch, T. M., Keiner, M. H. & Hollmann, H. 1997, 'No short-term effects of high-frequency electromagnetic fields on the mammalian pineal gland', *Bioelectromagnetics,* vol. 18, pp. 376-387.
Vorobyov, V. V, Galchenko, A.A., Kukushkin, N. I. & Akoev, I. G. 1997, 'Effects of weak microwave fields amplitude modulated at ELF on EEG of symmetric brain areas in rats', *Bioelectromagnetics,* vol. 18, pp. 293-298.
Wagner, P., Röschke, J., Mann, K., Hiller, W. & Frank, C. 1998, 'Human sleep under the influence of pulsed radiofrequency electromagnetic fields: a polysomnographic study using standardized conditions', *Bioelectromagnetic*s, vol. 19, p. 199.
Wang, B. & Lai, H. 2000, 'Acute exposure to pulsed 2450 MHz microwave affects water-maze performance in rats', *Bioelectromagnetics*, vol. 21, pp. 52-56.
Wolke, S., Neibig, U., Elsner, R., Gollnick, F. & Meyer, R. 1996, 'Calcium homeostasis of isolated heart muscle cells exposed to pulsed high-frequency electromagnetic fields', *Bioelectromagnetics*, vol. 17, pp. 144-153.

Annex 5

Assessment of RF Exposure Levels

Due to the complex nature of radiated RF fields, persons wanting to perform field measurements should have a good knowledge of the instrumentation to be used and the techniques described in AS 2772.2-1988 (Standards Australia 1988). Appropriate training is necessary. AS 2772.2 describes the techniques and instrumentation used for the measurement of radiofrequency fields in the frequency range 100 kHz to 300 GHz for exposures occurring in the near and far-field of radiating sources.

Further helpful information is freely available in the Radiofrequency Radiation Dosimetry Handbook (Durney, Massoudi & Iskander 1986) available from www.brooks.af.mil/AFRL/HED/hedr/reports. The RF Radiation Safety Handbook (Kitchen 1993) provides a practical description when performing RF surveys for a variety of applications. The same book also describes the various commercial instruments and personal RF dosimeters.

While much of the basis for the limits recommended in this standard are derived from the SAR limits, the measurement of SAR may be impractical for other than device compliance testing or scientific research. In general, accepted methods of measurement of SAR include the rate of temperature rise within the exposed object or the measurement of the internal electric field strength. The temperature rise may be characterised by a whole-body-averaged (calorimetric) measurement, a point measurement (via a thermometer implanted in the body being exposed), or thermographic camera analyses of bisected phantom models. The SAR may be calculated when the tissue's electrical properties are known and the internal electric field strength is measured with an E-field probe.

Compliance with the limits specified in this Standard applies to measurement of one or more components of the electric field (**E**), or the magnetic field (**H**). An investigation of the nature of the radiating field should precede any measurement and should include; frequency, modulation, field polarisation and anticipated levels.

Commercially available instruments permit the measurement of the **E** and **H** reference levels referred to in this Standard. Assessment of a potential hazard for exposures that occur at frequencies less than 110 MHz may require assessment of induced body currents and contact currents.

Codes of practice are available and describe a safe means of operating potentially hazardous RF equipment. Where possible, relevant codes of practice should be referred to when advising on mitigation. Some of the relevant codes are as follows:

'Safety in the use of radiofrequency dielectric heaters and sealers' ILO No.71 Occupational and Health Safety Series
'Safe use in industry of Radio Frequency Generating Plant' Division of Workplace Health & Safety, Queensland.
'Code of practice for the safe use of microwave diathermy units (1985)' NH&MRC
'Code of practice for the safe use of shortwave diathermy units (1985)' NH&MRC

Far-field measurements

In the far-field the RF power flux density (S), the electric field strength (E), and magnetic field strength (H), are interrelated by the following expressions:

$S = E \times H$

$E = \sqrt{(Z \times S)} = \sqrt{(377\ S)}$, i.e. $E^2 = 377\ S$

$H = \sqrt{(S/Z)} = \sqrt{(S/377)}$, i.e. $H^2 = S/377$

$E = Z \times H$

where

E = electric field strength, in volts per metre

H = magnetic field strength, in amperes per metre

S = electromagnetic power flux density, in watts per square metre

Z = characteristic impedance of free space, in ohms $\approx 377\ \Omega$.

In the far-field of an RF source, relevant E, H and S limits will not be exceeded for frequencies above 10 MHz if any one of the RF power flux density (S), the electric field strength (E), or the magnetic field strength (H) can be shown to be less than the relevant limits specified in Tables 6, 7 and 8 in Section 2 of the Standard. At frequencies below 10 MHz in the far-field, measurements or evaluations of the E field are sufficient to determine compliance with E and H reference levels.

Near-field measurements

For a RF source operating at a frequency with a wavelength in air of λ m, the distance from the RF source to the reactive field boundary is $\lambda/2\pi$. In the reactive near-field, the field impedance, Z, will not necessarily be equal to 377 ohms. Therefore both electric and magnetic field strengths should be measured unless the impedance of the field is known.

However, in the radiating near-field it can be shown that the wave impedance is within 10% of the free space impedance at distances greater than about 0.5 λ from the antenna so that E, H or S may be measured to determine compliance with the reference levels. However, this approach should be cautiously adopted when making measurements near the reactive field boundary.

Many instruments which purport to measure RF power flux density actually measure the square of the electric or magnetic field strengths, but have a meter calibrated to indicate equivalent plane wave power flux density. The quantity sampled shall be deemed to be less than the reference level if such an instrument registers a value less than the equivalent level of RF power flux density for a plane wave. The expressions given in this Annex may be used to determine the equivalent level. There are instruments currently available that are able to measure H fields of frequencies of up to 300 MHz.

References

Durney, C.H., Massoudi, H. & Iskander, M.F. 1986, *Radiofrequency Radiation Dosimetry Handbook*, 4th edn, United States Air Force Research Laboratory Technical Report USAFSAM-TR-85-73, Brooks Air Force Base, Texas USA. [Refer www.brooks.af.mil/AFRL/HED/hedr/reports]

Kitchen, R. 1993, *The RF Radiation Safety Handbook*, Butterworth-Hienemann Ltd. [ISBN 0750617128]

Standards Australia 1988, *Radiofrequency radiation. Part 2: Principles and methods of measurement - 300 kHz to 100 GHz*', AS/NZS 2772.2, Standards Australia, Sydney Australia.

Annex 6

A Public Health Precautionary Approach to RF Fields

This Standard sets limits on the exposure to RF fields for persons in the occupational and general public settings. The limits are designed to prevent established health effects of heating, electro-stimulation and auditory response, and are set at a level that includes a safety margin.

There has been extensive debate as to whether RF causes any health effects below the level of exposure capable of causing demonstrable heating, and in particular whether there are any effects at or below the exposure limits. If any low-level RF effects occur, they are unable to be reliably detected by modern scientific methods. A degree of uncertainty remains about possible effects at low levels of exposure, mainly because it is difficult to establish the existence of any effect that occurs infrequently or is only weak or non-specific in nature. It is also very difficult to prove scientifically that effects never occur (Independent Expert Group on Mobile Phones [IEGMP] 2000).

In the public health field there is a movement to adopt precautionary (sometimes called cautionary) approaches for management of health risks in areas of scientific uncertainty. The philosophy of the precautionary approach is that 'where there are reasonable grounds for concern about a risk and there is uncertainty, decision makers should be cautious'. The precautionary approach has mainly been used in the field of environmental protection, often in situations where no statutory limits exist. The precautionary approach has subsequently been extended into other fields including health, to areas where there is uncertainty of risk (WHO 2000).

Since the concept of the precautionary approach was first developed there has been considerable controversy as to what the precautionary approach actually consists of, what triggers it and how it is to be applied. Over time the concepts have been refined, the issues and elements have become clearer, and as a more structured formulation, the term precautionary principle has been used.

When considering policies, there is a range of strategies that can be applied according to the nature of the hazard and the severity and frequency of health effects. At one extreme there are proven hazards with clearly defined health effects, while at the other extreme the agent may cause no known side effects, there is only uncertainty because of limitations of the knowledge about any possible hazard. Several different policies promoting caution have been developed in different contexts to address concerns about public, occupational and environmental health issues in the face of scientific uncertainty. These include the Precautionary Principle, ALARA (as low as reasonably achievable) and Prudent Avoidance. They are outlined briefly below.

1. The **Precautionary Principle** is a risk management policy applied in circumstances where there is scientific uncertainty. It is risk oriented and it is intended for use in drafting provisional responses to a specific, potentially serious health risk until more adequate data are available for a more scientifically based response. The precautionary principle should be considered as part of a structured approach to the analysis of risk, which comprises risk assessment, risk management and risk communication. The precautionary principle provides a means of applying the elements of risk management to situations where there is uncertainty.

One example where the precautionary principle was enshrined was at the Rio Conference on the Environment and Development 1992, during which the Rio Declaration was adopted, whose principle 15 states that: *'in order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost effective measures to prevent environmental degradation'* (United Nations General Assembly 1992).

On 2 February 2000, the European Commission approved an important communication on the precautionary principle providing guidelines for its application (Commission of the European Communities 2000). The EC document indicated that even though scientific data may be limited, there needs to be as complete assessment as possible of the risk. Judging what is an acceptable element of risk for society is a political responsibility. The concerns of the public have to be considered and the decision making process should be transparent and involve all interested parties. To trigger the precautionary principle there needs to be reasonable grounds for concern about a possible hazard.

That document indicated that where action is deemed necessary, measures based on the precautionary principle should be:

- proportional to the chosen level of protection,
- non-discriminatory in their application,
- consistent with similar measures already taken in equivalent areas in which all scientific data are available,
- based on examination of potential benefits and costs of action or lack of action (not just economic costs),
- subject to review in the light of new scientific evidence,
- capable of assigning responsibility for producing scientific evidence for a more comprehensive risk assessment.

Those guidelines could be applied to a variety of situations of varying risk.

2. **ALARA** is an acronym for **'As Low As Reasonably Achievable'**. It is a policy used to minimise known risks, by keeping exposures as low as is reasonably possible, taking into account risks, benefits to public health and safety, economic factors, technology and other societal factors. ALARA was specifically developed and applied in the context of ionizing radiation where it is supplementary to the limits (ICRP 1991). For ionizing radiation, the limits are set at a level where there is an acceptable risk. However, even below those limits, it is believed there is a low risk of stochastic health effects, and ALARA is designed to minimise that risk. In contrast to ionizing radiation, in the field of RF the scientific data suggests there is a threshold for health effects.

3. The concept of **prudent avoidance** was initially developed as a risk management strategy to deal with concern about possible effects from ELF electromagnetic fields from high tension power lines (Nuttall, Flanagan & Melik 1999). It has evolved to mean taking simple, easily achievable, low cost measures to reduce exposure to electromagnetic fields, even in the absence of a demonstrable risk. Generally, government agencies have applied the policy only to new facilities, where minor modifications in design can reduce levels of public exposure. It has not been applied to require modification of existing facilities, which is generally very expensive. Defined in this way, Prudent Avoidance prescribes taking low-cost measures to reduce exposure, in the

absence of any scientific proof that the measures would reduce risk. Such measures are usually couched in terms of broad recommendations rather than fixed rules.

Application of the precautionary approach to RF

With respect to RF, at very high levels of exposure significant thermal electro-stimulation and auditory effects occur, and the limits are designed to provide protection against those effects. At levels of RF exposure below the limits, the risk of any effect is low, but some uncertainty exists, and the precautionary approach could be applied (WHO 2000). The precautionary approach would be supplementary to the limits of the standard, as it strives to widen the margin of safety by promoting measures to keep exposure at levels even lower than the limits set in the standard.

This Standard already contains elements of precaution; for example, limits for the general public are lower than the occupational group, and there is special treatment of pregnant workers. However, a precautionary approach implies more than just adopting measures so as not to exceed the prescribed limits; it entails taking additional steps to provide a greater margin of safety by promoting measures to keep exposure lower than the limits (Foster, Vecchia & Repacholi 2000). The reports of Commission of the European Communities (2000), IEGMP (2000) and Zmirou (2001) considered application of the precautionary approach.

An application of the precautionary approach is encapsulated in clause 5.7 (e) of this Standard: '*Minimising, as appropriate, RF exposure which is unnecessary or incidental to achievement of service objectives or process requirements, provided this can be readily achieved at reasonable expense. Any such precautionary measures should follow good engineering practice and relevant codes of practice. The incorporation of arbitrary additional safety factors beyond the exposure limits of this Standard is not supported.*' In the occupational setting where the limits are higher, measures to keep exposure lower than the limits are encouraged through the mandatory application of risk management process outlined in Section 5.1. The measures that are applied so as to not exceed a RF limit, and those measures used to keep exposure somewhat lower than a limit often differ only in degree.

While a precautionary approach is an attractive concept in some parts of the community, care is required in its application (Cross 1996). The chief difficulty is the lack of evidence that any additional measures will offer any more protection against unknown risks, than that provided by just keeping within the prescribed general public RF limits. It is also important that the introduction of a particular measure does not inadvertently introduce an additional untoward effect in a different area. The consumer and society must ultimately meet costs, both direct and indirect.

Further scientific research should provide data that helps reduce the degree of uncertainty about the effects of exposure to RF. Hence the Standard and Codes of Practice will need review in the light of new scientific evidence.

Codes of Practice also have an important educational role, which can help reduce individual exposure, both public and occupational, to radiofrequency radiation. They do this by identifying potential areas of RF exposure, and giving advice on measures that individuals can take to reduce exposure to radiofrequency radiation.

References

Commission of the European Communities 2000, *Commission adopts communication on precautionary principle*, Commission of the European Communities, Brussels Belgium.
[Refer http://europa.eu.int/rapid/start/cgi/guesten.ksh]

Cross, F., B. 1996, 'The paradoxical perils of the precautionary principle', *Washington and Lee Law Review*, vol. 53, pp. 851-925.

Foster, K. R., Vecchia, P. & Repacholi, M., H. 2000, 'Science and the precautionary principle', *Science*, vol. 288, pp. 979-980.

ICRP 1991, 'Recommendations of the International Commission on Radiological Protection', Publication 60, *Annals of the ICRP*, vol. 21, no. 1-3.

Independent Expert Group on Mobile Phones 2000, *Mobile phones and health* (Sir William Stewart, Chairman), National Radiological Protection Board, Chilton, Didcot, UK.
[Refer www.iegmp.org.uk]

Nuttall, K., Flanagan, P. J. & Melik G. 1999, 'Prudent avoidance guidelines for power frequency magnetic fields', *Radiation Protection in Australasia*, vol. 16, no. 3, pp. 2-12.

WHO 2000, *Electromagnetic fields and public health cautionary policies*, World Health Organization, Geneva Switzerland.
[Refer www.who.int/peh-emf/publications/facts_press/EMF-Precaution.htm]

United Nations General Assembly 1992, *Report of the United Nations Conference on the Environment and Development*, 3-14 June, Rio de Janeiro Brazil.
[Refer www.un.org/documents/ga/conf151/aconf15126-1annex1.htm]

Zmirou, D. 2001, *Les téléphones mobiles, Leurs stations de base et la santé* (Mobile phones, their base stations, and health), Direction générale de la santé (General Directorate of Health), Paris France.
[Refer www.sante.gouv.fr/htm/dossiers/telephon_mobil/teleph_uk.htm]
Note: the full report is available in both French and English.

Annex 7

Placement Assessment of Persons Occupationally Exposed to RF Fields

This assessment is conducted for the purpose of placing an employee in RF work and to provide a baseline on health status in the event of an overexposure.

(a) Pre-placement

A pre-placement health assessment for employees who will be occupationally exposed to RF levels in excess of non-occupational levels is required. This may be achieved by a self-administered questionnaire (an example is shown in Figure A1) which should provide baseline occupational and relevant medical history information, and must identify the presence of:

(i) *Surgically-implanted medical devices* susceptible to RF fields e.g. conductive/metallic devices which may re-distribute incident RF energy, such as metallic implants and prostheses (excluding dental work) and electronic treatment devices which may be susceptible to interference (e.g. pacemakers). Where such a device exists the matter should be referred (including by phone) to an appropriate medical specialist knowledgeable in the medical effects of RF exposures who should liaise with the person's treating doctor and appropriate technical advisers. This is to enable an assessment to be made regarding suitability for RF work.

(ii) *Pregnancy*

A positive response to enquiry about pregnancy must lead to implementation of relevant personnel policy and procedures which must reduce exposure to general public limits for the remaining duration of the pregnancy (see Clause 5.2).

(b) Routine or periodic monitoring

There is no requirement for periodic monitoring, however employers of RF workers need to maintain adequate estimates of RF exposure in respect of both individual workers and particular tasks. If monitoring for research purposes is required, this should be specifically designed to achieve the purpose.

RADIOFREQUENCY WORKERS MEDICAL ASSESSMENT

Surname	Given Name	Sex	Age	Birthdate
				/ /
Work Location			Work Phone ( )	
Home Address			Home Phone ( )	

This exam is conducted for the purpose of placing you in RF work and to provide a baseline on your health status in the event of an overexposure.

History

A: Do you have any of the following? Please circle your answer: Y= yes, N= no

Disorders of the eye (except for reading glasses)	Y	N
Any medical implants (e.g. metal rods) or devices (e.g. pacemaker) (except for dental fillings and plates)	Y	N
Disorders of the nervous system	Y	N
Disorders of reproduction	Y	N

If you answer Yes you may be referred for further medical assessment.
In the event of an eye examination being conducted it is suggested the Attached pro forma be used to assist uniform data recording

B: (women) Are you pregnant? Y N

Pregnancy is not a bar to working with radiofrequency radiation and it has not been proven to be hazardous to the foetus but your exposures will be reduced during your pregnancy to accord with the Australian safety limits for members of the general public.

Figure A1 Example medical assessment questionnaire [page 1 of 3]

Model Eye Examination

Visual acuity

Snellen notation at 6 m with record of letters incorrect at smallest line seen
e.g.:(6/4.5 –3)

	RE	LE
Unaided visual acuity		
Visual acuity with present correction, if any		
Corrected visual acuity by refraction (if different)		

Refraction

SPH	CYL	AXIS	SPH	CYL	AXIS

Binocularity

Is there a strabismus? Yes No
If yes, describe…..
If no strabismus
Heterophoria (in prism dioptres)
Distance Horizontal….. Vertical…..
Near Horizontal….. Vertical…..

Colour vision normal?

More than 3 errors on Ishihara (24 plates) Yes No

External eye examination

Ocular adnexa normal? Yes No
Pupils normal? Yes No
Iris normal? Yes No
If no, describe…...

Intraocular pressure (record in mm Hg) RE LE
Slit lamp examination (pupil dilated)

Cornea normal? Yes No
Anterior chamber normal? Yes No
Record any abnormality…..
Any lens opacity? Detail lens opacities on adjacent page Yes No

Ophthalmoscopic examination

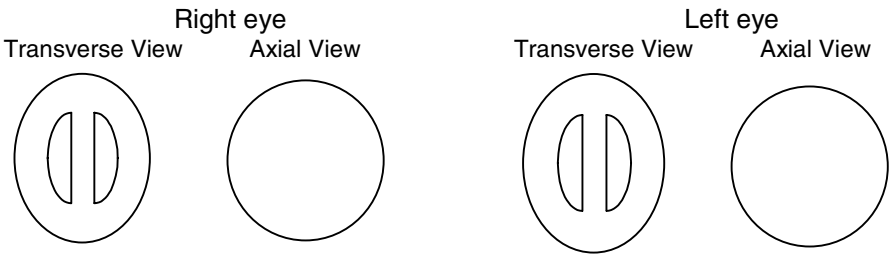
Ocular fundus: posterior pole and periphery normal? Yes No
Describe any abnormality…...

Figure A1 Example medical assessment questionnaire - continued [page 2 of 3]

Classification of lens opacity

	RE	LE
1. Congenital		
1.1 Blue dot		
1.2 Coronary/club		
1.3 Axial embryonic		
1.4 Satural/stellate		
1.5 Anterior polar		
1.6 Posterior polar		
1.7 Nuclear		
2. Age related		
2.1 Cortical lamellar superation		
2.2 Cortical spokes/wedges		
2.3 Cortical vacuoles		
2.4 Nuclear brunescence		
3. Secondary/Trauma/Toxic		
3.1 Contusion or penetrating injury		
3.2 Equatorial vacuoles		
3.3 Posterior capsular		
3.4 Posterior sub-capsular		
3.5 Posterior polychromatic lustre		
3.6 Anterior capsular/sun capsular		
3.7 Diabetic (snowflake) cataract		
3.8 Other not classified above		
4. Aphakic or pseudo aphakic		
4.1 Aphakic or pseudo aphakic		

Draw the location and extent of any opacity



Description.....

Figure A1 Example medical assessment questionnaire - continued [page 3 of 3]

Annex 8

Radiation Protection and Regulatory Authorities

TABLE A1: RADIATION PROTECTION AUTHORITIES

Where advice or assistance is required from the relevant radiation protection authority, it may be obtained from the following officers (refer www.arpansa.gov.au for updates):

COMMONWEALTH, STATE / TERRITORY	CONTACT
Commonwealth	Director, Regulatory Branch ARPANSA PO Box 655 Tel: (02) 9545 8333 Miranda NSW 1490 Fax: (02) 9545 8348 Email: arpansa@health.gov.au
New South Wales	Director, Radiation Control Section Environment Protection Authority P.O. Box A290 Tel: (02) 9995 5000 Sydney South NSW 1232 Fax: (02) 9995 5925 Email: info@epa.nsw.gov.au
Queensland	Director, Radiation Health Department of Health 450 Gregory Terrace Tel: (07) 3406 8000 Fortitude Valley QLD 4006 Fax: (07) 3406 8030 Email: radiation_health@health.qld.gov.au
South Australia	Manager, Radiation Section Department of Human Services PO Box 6 Rundle Mall Tel: (08) 8130 0700 Adelaide SA 5000 Fax: (08) 8130 0777 Email: radiation@dhs.sa.gov.au
Tasmania	Senior Health Physicist Department of Health & Human Services GPO Box 125B Tel: (03) 6222 7256 Hobart TAS 7001 Fax: (03) 6222 7257 Email: health.physics@dhhs.tas.gov.au
Victoria	Manager, Radiation Safety Unit Department of Human Services GPO Box 4057 Tel: (03) 9637 4167 Melbourne VIC 3001 Fax: (03) 9637 4508 Email: radiation.safety@dhs.vic.gov.au
Western Australia	Secretary Radiological Council Locked Bag 2006 Tel: (08) 9346 2260 Nedlands WA 6009 Fax: (08) 9381 1423 Email: radiation.health@health.wa.gov.au
Australian Capital Territory	Director, Radiation Safety Section Department of Health, Housing and Community Care GPO Box 825 Tel: (02) 6207 6946 Canberra ACT 2601 Fax: (02) 6207 6966 Email: radiation.safety@act.gov.au
Northern Territory	Manager, Radiation Health Radiation Health Section Department of Health & Community Services GPO Box 40596 Tel: (08) 8999 2939 Casuarina NT 0811 Fax: (08) 8999 2530 Email: envirohealth@nt.gov.au

TABLE A2: REGULATORY AUTHORITIES

The following organisations regulate various aspects of the use of radiofrequency fields:

COMMONWEALTH, STATE / TERRITORY	CONTACT
Commonwealth (i) for communications	Standards & Compliance Group Australian Communications Authority PO Box 78 Tel: (02) 6219 5555 Belconnen ACT 2616 Fax: (02) 6219 5200 Email: emr.issues@aca.gov.au
(ii) for other than communications	Director, Regulatory Branch ARPANSA PO Box 655 Tel: (02) 9545 8333 Miranda NSW 1490 Fax: (02) 9545 8348 Email: arpansa@health.gov.au
New South Wales	[No regulator]*
Queensland	Division of Workplace Health & Safety, Department of Industrial Relations, GPO Box 69, Tel: (07) 3225 2000 Brisbane Qld 4001 Fax: (07) 3247 4519 Web: www.detir.qld.gov.au
South Australia	Manager, Radiation Section Department of Human Services PO Box 6 Rundle Mall Tel: (08) 8130 0700 Adelaide SA 5000 Fax: (08) 8130 0777 Email: radiation@dhs.sa.gov.au
Tasmania	Workplace Standards Tasmania Department of Infrastructure Energy and Resources PO Box 56 Tel: (03) 6233 7657 Rosny Park Tas 7018 Fax: (03) 6233 8338 Email: wstinfo@dier.tas.gov.au
Victoria	[No regulator]*
Western Australia	Secretary Radiological Council Locked Bag 2006 Tel: (08) 9346 2260 Nedlands WA 6009 Fax: (08) 9381 1423 Email: radiation.health@health.wa.gov.au
Australian Capital Territory	ACT Workcover PO Box 224 Civic Square ACT 2608 Tel: (02) 6205 0200 Email: workcover@act.gov.au Fax: (02) 6205 0797 Web: www.workcover.act.gov.au
Northern Territory	[No regulator]*

Tables A1 and A2 were correct at the time of publication but are subject to change from time to time. For the most up to date list the reader is advised to consult the ARPANSA web site at www.arpansa.gov.au.

* In these jurisdictions, while there is no special regulation of RF exposure, Occupational Health & Safety Legislation applies.

Annex 9

ARPANSA Radiation Protection Series Publications

ARPANSA has taken over responsibility for the administration of the former NHMRC Radiation Health Series of publications and for the codes developed under the *Environment Protection (Nuclear Codes) Act 1978*. The publications are being progressively reviewed and republished as part of the *Radiation Protection Series*. Current publications in the *Radiation Protection Series* are:

RPS 1. Recommendations for Limiting Exposure to Ionizing Radiation (1995) and National Standard for Limiting Occupational Exposure to Ionizing Radiation (republished 2002)

RPS 2. Code of Practice for the Safe Transport of Radioactive Material (2001)

RPS 3. Radiation Protection Standard for Maximum Exposure Levels to Radiofrequency Fields – 3 kHz to 300 GHz (2002)

Those publications from the NHMRC Radiation Health Series and the *Environment Protection (Nuclear Codes) Act* Series that are still current are:

RADIATION HEALTH SERIES

RHS 2. Code of practice for the design of laboratories using radioactive substances for medical purposes (1980)

RHS 3. Code of practice for the safe use of ionizing radiation in veterinary radiology: Parts 1 and 2 (1982)

RHS 4. Code of practice for the safe use of radiation gauges (1982)

RHS 5. Recommendations relating to the discharge of patients undergoing treatment with radioactive substances (1983)

RHS 8. Code of nursing practice for staff exposed to ionizing radiation (1984)

RHS 9. Code of practice for protection against ionizing radiation emitted from Xray analysis equipment (1984)

RHS 10. Code of practice for safe use of ionizing radiation in veterinary radiology: part 3-radiotherapy (1984)

RHS 11. Code of practice for the safe use of soil density and moisture gauges containing radioactive sources (1984)

RHS 12. Administration of ionizing radiation to human subjects in medical research (1984)

RHS 13. Code of practice for the disposal of radioactive wastes by the user (1985)

RHS 14. Recommendations for minimising radiological hazards to patients (1985)

RHS 15. Code of practice for the safe use of microwave diathermy units (1985)

RHS 16. Code of practice for the safe use of short wave (radiofrequency) diathermy units (1985)

RHS 17. Procedure for testing microwave leakage from microwave ovens (1985)

RHS 18. Code of practice for the safe handling of corpses containing radioactive materials (1986)

RHS 19. Code of practice for the safe use of ionizing radiation in secondary schools (1986)

RHS 20. Code of practice for radiation protection in dentistry (1987)

RHS 21. Revised statement on cabinet X-ray equipment for examination of letters, packages, baggage, freight and other articles for security, quality control and other purposes (1987)

RHS 22. Statement on enclosed X-ray equipment for special applications (1987)

RHS 23. Code of practice for the control and safe handling of radioactive sources used for therapeutic purposes (1988)

RHS 24. Code of practice for the design and safe operation of non-medical irradiation facilities (1988)

RHS 25. Recommendations for ionization chamber smoke detectors for commercial and industrial fire protection systems (1988)

RHS 26. Policy on stable iodine prophylaxis following nuclear reactor accidents (1989)

RHS 28. Code of practice for the safe use of sealed radioactive sources in bore-hole logging (1989)

RHS 29. Occupational standard for exposure to ultraviolet radiation (1989)

RHS 30. Interim guidelines on limits of exposure to 50/60Hz electric and magnetic fields (1989)

RHS 31. Code of practice for the safe use of industrial radiography equipment (1989)

RHS 32. Intervention in emergency situations involving radiation exposure (1990)

RHS 34. Safety guidelines for magnetic resonance diagnostic facilities (1991)

RHS 35. Code of practice for the near-surface disposal of radioactive waste in Australia (1992)

RHS 36. Code of practice for the safe use of lasers in schools (1995)

RHS 37. Code of practice for the safe use of lasers in the entertainment industry (1995)

RHS 38. Recommended limits on radioactive contamination on surfaces in laboratories (1995)

ENVIRONMENT PROTECTION (NUCLEAR CODES) ACT SERIES

Code of Practice on the Management of Radioactive Wastes from the Mining and Milling of Radioactive Ores 1982

Code of Practice on Radiation Protection in the Mining and Milling of Radioactive Ores 1987

Contributors to Drafting and Review

WORKING GROUP

Chair:

Dr Colin Roy,	Director, Non-ionizing Radiation (NIR) Branch, ARPANSA

Members:

Dr Vitas Anderson,	Biophysicist, EME Australia Pty Ltd
Mr Wayne Cornelius,	Head, Electromagnetic Radiation Section (EMR), NIR Branch, ARPANSA
Mr Dan Dwyer,	Lawyer - Communications, Electrical & Plumbing Union
Dr Bruce Hocking,	Consultant in Occupational Medicine
Dr Ken Joyner,	Health Physicist, Australian Mobile Telecommunications Association.
Mr John Lincoln,	Convenor, Electromagnetic Radiation Alliance of Australia
Dr Andrew Wood,	Senior lecturer in Biophysics, Swinburne University of Technology
Ms Jill Wright,	Principal Adviser, Division of Workplace Health & Safety, Queensland

Consultants:

Dr David Black,	Occupational & Environmental Physician
Professor Mark Elwood,	Epidemiologist & Public Health Medicine Specialist (Director, National Cancer Control Initiative)

Secretariat:

Mr Michael Bangay,	Technical Specialist, EMR Section, NIR Branch, ARPANSA
Mr Alan Melbourne,	Manager, Standards Development & Committee Support Section, ARPANSA

Observers:

Dr Graeme Dickie,	Radiation Health & Safety Advisory Council (Deputy Director of Oncology Royal Brisbane Hospital)
Dr Stuart Henderson,	Physicist, EMR Section, NIR Branch, ARPANSA
Mr Ken Karipidis,	EME Manager, EMR Section, NIR Branch, ARPANSA
Ms Patricia Healy,	Research Coordination & Facilitation National Occupational Health & Safety Commission
Mr Ian McAlister,	Manager, Radiocommunications Standards, Australian Communications Authority

In addition:

Mr David McKenna,	National Organiser, Community & Public Sector Union resigned and was replaced by Mr Dwyer.
Ms Judith Lawson,	Manager, Research Coordination Unit, Prevention Strategies & Facilitation Branch, National Occupational Health & Safety Commission resigned and was replaced by Ms Healy.

ORGANISATIONS/PERSONS CONTRIBUTING TO THE DEVELOPMENT OF THE PUBLICATION

The assistance of Standards Australia in granting permission for the working group to use the 1999 ballot draft prepared by Standards Australia Committee TE/7 is gratefully acknowledged.

Index

E

F

G

H

P

R