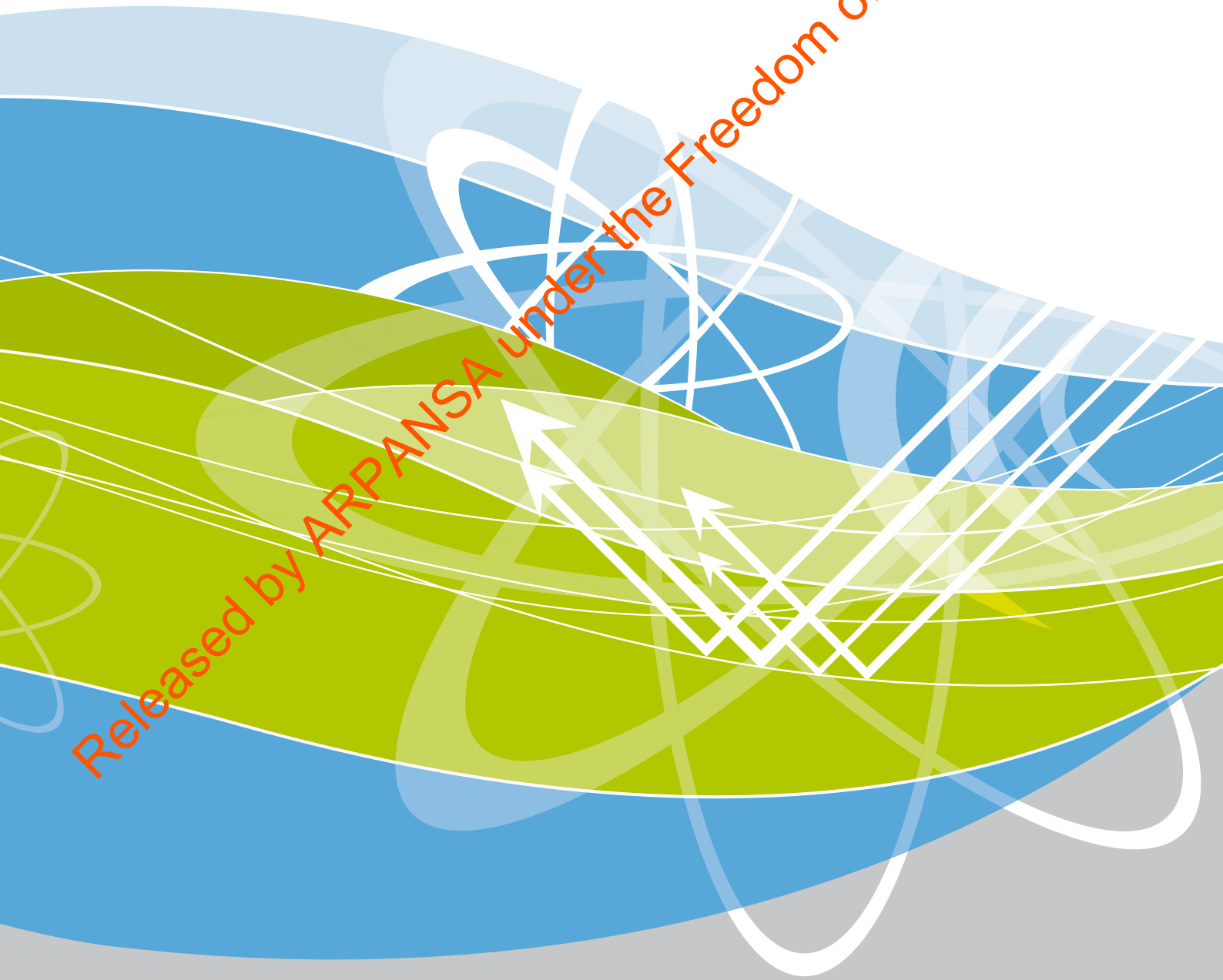
Australian Government
Australian Radiation Protection and Nuclear Safety Agency

Report by the ARPANSA Radiofrequency Expert Panel

Review of Radiofrequency Health Effects Research – Scientific Literature 2000 – 2012



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Report by the

ARPANSA Radiofrequency Expert Panel

on

Review of Radiofrequency Health Effects Research – Scientific Literature 2000 – 2012

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ARPANSA Perspective

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) published the Radiation Protection Standard '*Maximum Exposure Levels to Radiofrequency Fields - 3 kHz to 300 GHz*' in May 2002 (ARPANSA, 2002 – referred to in this document as the 'Standard' or 'RPS3'). The Standard sets limits for human exposure to radiofrequency (RF) fields in the frequency range 3 kHz to 300 GHz which may be produced from various sources including mobile telephone handsets and base stations as well as radio and television transmitters, other wireless devices and industrial sources. The Standard provides the basis for the regulation by the Australian Communications and Media Authority of RF exposure to members of the public from licensed radio transmitters.

The 2002 Standard was prepared by a working group established under the auspices of the ARPANSA Radiation Health Committee (RHC). While the International Commission on Non-Ionizing Radiation Protection (ICNIRP) 1998 exposure guidelines provided the initial basis for the 2002 Standard, further material was considered, including all relevant literature up to a cut-off date (about 2000) prior to the publication of the Standard. Overall harmonisation with ICNIRP was considered important and the exposure limits in RPS3 differ only in small detail from those in the ICNIRP guidelines.

Notwithstanding the large body of research underpinning the existing exposure limits, the issue of whether or not they are adequate to provide complete protection from harmful effects of exposure to RF fields remains a subject of research and of active debate within the scientific and wider community. At the time the Standard was prepared, it was recognised that new scientific research may indicate that changes may need to be made to the limits or the implementation of the Standard.

Since the year 2000, research in the area of RF and health has grown rapidly and several major research programs and reviews have been undertaken internationally. Since the cut-off date of the examination of scientific literature for RPS3, ARPANSA has identified more than 1300 publications relevant to the understanding of possible health effects of RF electromagnetic fields. These include the review by the International Agency for Research on Cancer (IARC) in 2011 (Baan et al., 2011) that resulted in the classification of RF fields as possibly carcinogenic but which did not assess the magnitude of any risk to health, and the 13-country INTERPHONE epidemiological study in 2010 (INTERPHONE Study Group, 2010). In addition, several countries, or groups of countries, have undertaken one or more comprehensive reviews of the subject, such as the recent review conducted by the Health Protection Agency in the UK in 2012 (HPA, 2012).

In July 2012 ARPANSA established a Radiofrequency Expert Panel with the task of making an assessment of the scientific literature to determine whether there are any significant changes to the science underpinning the 2002 Standard and to advise whether it continues to provide adequate protection. The Expert Panel conducting the review comprised three Australian academics who are experts in the areas of biophysics, experimental research and epidemiology as well as ARPANSA scientific staff. Members of the Expert Panel independently examined the major reviews and key individual papers in their area of expertise and identified issues that have arisen in the research since the publication of RPS3.

In their findings in this Report, the Expert Panel notes that since the preparation of RPS3 there have been significant advances in the science. Based on the assessment of the scientific evidence from January 2000 till August 2012, the Expert Panel find that the underlying basis of the ARPANSA RF exposure Standard remains sound and that the exposure limits in the Standard continue to provide a high degree of protection against the known health effects of RF electromagnetic fields.

However, the Expert Panel find that while the exposure limits of RPS3 are still valid for protection against known adverse effects, under some circumstances the margin of safety between these limits and the threshold for harmful effects may be less than originally intended.

While the findings of the Expert Panel in this Report provide confidence that the 2002 Standard provides adequate protection, they identify areas where RPS3 and its annexes could be updated to take account of increased knowledge and to better harmonise with international standards.

In recognition of the limitations on scientific knowledge of potentially harmful effects, the 2002 Standard includes a precautionary minimisation requirement for exposure to members of the public. Based on the findings of the Expert Panel, ARPANSA will give consideration to whether the precautionary elements of the standard should be clarified and extended to occupational exposure.

ARPANSA will continue to monitor the scientific research on RF fields and health and to monitor, in particular, the national cancer incidence trends and emerging trends in the use of RF.

ARPANSA would like to acknowledge the work of the external experts, Prof. Andrew Wood, Prof. Rodney Croft and Dr Geza Benke, and the ARPANSA staff, Dr Lindsay Martin, Dr Ken Karipidis and Don Wijayasinghe in the preparation of this report.

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March 2014

Contents

PART 1

1. Introduction

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) published the Radiation Protection Standard '*Maximum Exposure Levels to Radiofrequency Fields - 3 kHz to 300 GHz*' in 2002 (referred to in this document as the 'Standard' or 'RPS3'). At the time the Standard was prepared, it was recognised that new scientific research may indicate that changes may need to be made to the limits or the implementation of the Standard. With this in mind, ARPANSA has continued to monitor the research and expert reviews.

Since the cut-off date of the examination of scientific literature for RPS 3 (about 2000), ARPANSA has identified more than 1300 publications in the relevant areas of study, including the report of the 13-nation Interphone study (2010), and important reviews by the International Commission on Non-Ionizing Radiation Protection, (ICNIRP) (2009), the International Agency for Research on Cancer, (IARC) (Baan et al., 2011), the Health Protection Agency, (HPE), in the UK (AGNIR, 2012) and others. A list of major reviews and research programs on RF and health since the publication of RPS3 is given in Appendix 1. Based on 'limited evidence'[1] in humans and experimental animals, in 2010, IARC classified RF as 'possibly carcinogenic to humans'.

In July 2012 ARPANSA established an RF Expert Panel to assess the scientific literature to formally determine whether there are any significant changes to the science underpinning the Standard and whether it continues to provide adequate protection. The terms of reference for this 'Expert Panel' are presented in Appendix 2. The Panel comprised three Australian academics who are experts in the areas of biophysics, human provocation research and epidemiology as well as three ARPANSA scientific staff. A list of the members of the Expert Panel is provided in Appendix 3. The experts were invited to join the panel by ARPANSA based on their academic involvement and experience in the area of RF and health. Summaries of the relevant qualifications and credentials of the academic experts are presented in Appendix 4.

The ARPANSA RF Expert Group considered four main areas of scientific research relevant to the understanding of possible health effects of RF electromagnetic fields: in vitro/in vivo research, epidemiological research, human provocation research and RF dosimetry research.

[1] IARC defines 'limited evidence of carcinogenicity' as a positive association that has been observed between exposure to the agent and cancer for which a causal interpretation is considered to be credible, but chance, bias or confounding could not be ruled out with reasonable confidence.

2. Expert Panel Methodology

The RF Expert Panel review was based on an assessment of the published literature, including scientific papers, specialist reviews and literature summaries.

IN VITRO/IN VIVO RESEARCH

One way of looking for possible harmful effects is through the exposure of living cells (or other components of an organism) outside the human or animal (in vitro) or through the exposure of living animals (in vivo). In either case, one can look for increases in disease, for changes in physiology, or for subtle biochemical or other changes than might help predict possible harmful effects on humans or the environment.

HUMAN PROVOCATION RESEARCH

Perhaps the most direct way to study possible harmful effects is to deliberately expose human volunteers under controlled circumstances in what are termed human provocation studies. Ethical and practical considerations generally limit these studies to short-term exposures and to the examination of acute effects such as changes to physiology or perceptions by the subject.

DOSIMETRY

The science of radiofrequency dosimetry provides the link between the external and internal electric and magnetic fields and radiation, and the deposition of energy within the living cells and other structures of the human body. It allows the interpretation of experiments performed on humans or animals, and allows the extension of these results to other exposure situations.

EPIDEMIOLOGY

While the results of in vivo and in vitro research can be difficult to apply directly to human health, the field of epidemiology provides a means of examining the incidence of human disease in real-life situations. This area of research hopes to link increases in disease to a particular chemical, life-style or agent such as RF electromagnetic fields. However, because the exposures are not controlled as in a laboratory study, the results can be difficult to interpret.

Specific methodologies were employed by the experts in reviewing their area of expertise, including their method of evaluation of studies. These are described in more detail in the later sections.

2.1 Expert Panel Processes

The Expert Panel met on two occasions:

a. On 8 August 2012 to plan the RF review. The Expert Panel agreed that:

- The academic experts would look at the published literature and investigate special focus areas.

- The academic experts would identify any issues that may have arisen in the research since the publication of RPS3.
- ARPANSA would identify special areas of investigation for the academic experts.
- The relevant expert would also look at dosimetric issues that have arisen since the publication of RPS3.

b. On 27 September 2012 to discuss special focus areas and to plan the final report. The Expert Panel agreed on:

- A set of findings based on the assessment of the scientific evidence.
- The structure of the final report.

2.2 RF Literature Database

Prior to the formation of the Expert Panel, ARPANSA collected studies on RF and health-related outcomes published since the year 2000. The methods employed by ARPANSA in identifying the studies are described in detail in Appendix 5. The RF literature database assembled by ARPANSA includes 1354 studies with health/biological outcomes from January 2000 till August 2012 (298 epidemiological, 238 human/provocation, 453 in vivo and 365 in vitro). The database also includes 72 major reviews or specialist reviews on in vivo/in vitro research published during that period. The academic experts in the panel were not restricted to considering the studies collected by ARPANSA and were able to take into account any other studies.

2.3 RF Literature Summaries

Summaries on the epidemiological and human/provocation research were prepared by ARPANSA staff in order to assist the experts in the panel representing these particular areas of research. Due to the wide range of specialised research topics found within the published in vivo and in vitro research, similar summaries were not prepared by ARPANSA staff. Instead, ARPANSA collected in vivo/in vitro summaries prepared for health authorities or for peer-reviewed journals by expert individuals or group of scientists and made these available to the academic experts in the panel.

3. Expert Panel Assessment

This review has been prepared to advise ARPANSA on the current scientific knowledge and its relevance as interpreted by the members of the Expert Panel.

The detailed individual Expert assessments are provided in the later sections, but in summary, in the specific areas studied, the Experts found:

IN VITRO/IN VIVO RESEARCH

While in vitro/in vivo studies give indications of some effects, these often appear to occur at levels higher than typical exposures or relate to subtle biological effects not necessarily related to disease, and with effects to date that are not apparently replicable. Accordingly, based on the in vitro/in vivo research, there is no evidence of a need for the reconsideration of the exposure limits in RPS3.

Since 2000, there have been a number of nationally and internationally-funded research programs in relation to the safety of mobile telecommunications, many having an in vitro/in vivo component. Many of the research topics continue the issues discussed in Annex 4 of RPS3 and have been informed to a certain extent by the World Health Organization (WHO) RF Research Agendas (the most recent being WHO, 2010). In addition, there have been some significant advances in the study of possible mechanisms for non-thermal effects as well as bioeffects and applications of millimetre waves and terahertz radiation. There are clearly new topics of research which need consideration and views formed on whether the newer evidence strengthens the summaries presented in RPS3 or otherwise. Although the papers published since 2000 would appear roughly balanced (47% 'effect'; 53% 'no effect'), this does not take into account such considerations as: publication bias; internal consistency; methodological weakness or dosimetric rigour.

Most discipline-based reviews conclude thermal effects to be adequate to explain the observed data. Overall, it seems unlikely that there is any need to revise the conclusion that the Basic Restrictions should be based on thermal effects and electrostimulation. However, the rationale for a precautionary approach may need to be clarified in light of the growth in the body of knowledge over the last 10 years.

HUMAN PROVOCATION RESEARCH

Numerous studies since 2000, employing both self-reported hypersensitive individuals and healthy human volunteers, have investigated a range of effects (such as cognitive effects, cardiovascular effects, subjective symptoms etc) from RF exposure and predominantly mobile phone use and these are summarised by various major reviews (e.g. ICNIRP, 2009; SCENIHR, 2009; AGNIR 2012). There is no human provocation evidence from any of the major reviews that raises any doubt about the adequacy of the limits described in RPS3. Further, there is no additional human provocation research that demonstrates that the RPS3 limits are inadequate for protecting humans. It is noted that this research is mostly limited to healthy young adults, which raises the possibility that other groups (e.g. children, the elderly and the ill) may not be represented by this research. However no evidence or argument is given suggesting that such populations may be differentially affected by RF fields.

Therefore, based on the human provocation research, there is no evidence of a need for the reconsideration of the exposure limits in RPS3.

DOSIMETRY

Examination of the dosimetry research confirms that the RPS3 Basic Restrictions and Reference Levels continue to provide high levels of protection against the known thermal effects.

The development of realistic digital models of the human anatomy (phantoms) for a variety of body sizes (including newborn infants) represents a major advance in RF dosimetry in the last decade. Research utilising this improved dosimetry has not identified any health effects associated with exposures within RPS3. However, there is growing evidence that the limits for exposure from a distant source on electric and magnetic fields in RPS3 are not as conservatively formulated in some frequency range as was earlier thought and that while there are no likely health impacts, the safety margins built into the RPS3 exposure limits, in some frequency ranges for certain body sizes, may not be as conservative as originally thought.

In addition, there is the question of whether the localised deposition of RF energy in living tissue, the basis for the exposure limits of RPS3, continues to be an accurate predictor of local temperature rise in living tissue and hence of the degree of protection against biochemical changes, such as denaturation or proteins, changes in cell processes and other adverse thermal effects.

EPIDEMIOLOGY

Since the publication of RPS3 in 2002, there have been many epidemiological publications examining cancer/non-cancer outcomes and RF exposure, especially those associated with mobile phone use. Although the epidemiology in the past decade has improved our understanding of the limitations of exposure assessment and the likely extent of RF exposure to humans, the epidemiology of exposures to RF electromagnetic fields has not progressed with any dose-response relationships regarding carcinogenic and non-carcinogenic effects which would warrant significant changes to RPS3.

4. Findings

The following are the findings agreed by the Expert Panel. The more detailed rationales for how the Expert Panel decided on these findings are presented in the following Section 5 – 9.

Overall findings

1. Since the preparation of RPS3 there have been significant advances in the science.
2. The examination of the science in this area from January 2000 till August 2012 by the Expert Panel indicates that the Basic Restrictions of RPS3 are still valid for protection against known adverse effects.
3. Advances in numerical dosimetry suggest that under certain circumstances, RPS3 Reference Levels are not as conservative, relative to the Basic Restrictions, as originally thought. However, there is no evidence that this marginal difference in conservatism impacts on health in relation to RPS3.
4. The rationale and current text in RPS3 no longer accurately represents, in all respects, the current state of scientific understanding and needs to be brought up to date.
5. The RPS3 annexes, describing the significance of various research studies, no longer accurately represent, in all respects, the current state of scientific understanding and needs to be brought up to date at some stage.
6. The uncertainty about the absolute safety of exposures below the current RPS3 limits remains and consideration should be given whether the existing precautionary minimisation requirements of RPS3 address those uncertainties.

PART 2

5. Expert Assessment of In vitro/in vivo research

Prof. Andrew Wood

This section examines in vitro/in vivo research and notes that while in vitro/in vivo studies give indications of some effects, these often appear to occur at levels higher than typical exposures or relate to subtle biological effects not necessarily related to disease, and with effects to date that are not apparently replicable. Accordingly, based on the in vitro/in vivo research, there is no evidence of a need for the reconsideration of the exposure limits in RPS3.

Since 2000, there have been a number of nationally and internationally-funded research programs in relation to the safety of mobile telecommunications, many having an in vitro/in vivo component. Many of the themes continue the issues discussed in Annex 4 of RPS3 and have been informed to a certain extent by the WHO RF Research Agendas (the most recent being WHO, 2010). In addition, there have been some significant advances in the study of possible mechanisms for non-thermal effects, bioeffects and applications of millimetre waves and Terahertz (THz) radiation. The most useful recent review is that of the HPA (AGNIR, 2012), which tabulates studies since 2003 under several headings as shown below (Y = effect; N = no effect).

5.1 In vitro

Topic	Y	N
Genotoxic effects	16	32
Proliferation/apoptosis	25	30
Gene expression	4	10
Stress response/ Heat Shock Protein	4	17
Intracellular signalling	1	3
Membrane effects	17	4
Direct effect on proteins	15	1

It is interesting to note that the first five of these topics represent issues which have had a history of concern, stretching back to the period covered by RPS3 Annex 4. The last two represent the application of more recently developed techniques and may represent a publication bias. The Australian study on sperm motility (De Iuliis et al., 2009) is one that has captured some media attention and in common with many recent in vitro experiments reporting RF effects have pointed to the production of Reactive Oxygen Species (ROS) as a possible link between RF exposure and adverse bio-effects. However, the putative link between RF energy and altered ROS production remains tenuous. The work of several research groups, including that at Oxford University, on the possible role of retinal cryptochromes and associated free radical lifetimes in avian magneto-reception continues to provoke debate (Solov'yov and Schulten, 2009),

the link with RF being via experimental data showing altered flight patterns in birds exposed to low MHz RF, supported by theoretical analysis (Henbest et al., 2004), (Timmel and Henbest, 2004). However, the relevance of this work to mobile telecommunications frequencies is unclear.

In view of the wide-spread use of MRI systems, it is important to pay attention to any reports of adverse effects associated with the RF exposure in these systems, including, for example, suggestions of genotoxicity (Lee et al., 2011).

In addition to the frequencies covered by the AGNIR report, there has also been considerable interest in the frequencies above 30 GHz and extending to the THz range. These frequencies are used in some types of airport scanner and are being investigated for medical imaging applications. A recent review by Ziskin (Ziskin, 2012) covers some of the work at millimetre waves, whereas there is a growing database of studies at THz.

5.2 In vivo

The AGNIR review (AGNIR, 2012) has also tabulated outcomes from over 100 studies involving exposure to live animals and the subsequent analysis of tissue, physiological function or behaviour for indications of biological effects at levels mainly relevant to human exposures. These are summarised below:

	Topic	Y	N
1.	Brain and Nervous Tissue effects		
1.1	Cell physiology, injury, apoptosis	21	17
1.2	Neurotransmitters	1	1
1.3	Brain electrical activity	3	2
1.4	Blood-brain barrier and microcirculation	4	8
1.5	Autonomic function	0	2
2.	Behaviour		
2.1	Spatial memory tasks	7	4
2.2	General Learning tasks	4	5
3	Endocrine system	3	5
4	Auditory function	4	7
5	Genotoxicity and mutagenesis	8	10
6	Tumour incidence: normal strains	1	4
7	Tumour incidence: tumour-prone strains	2?	3
8	Co-carcinogenesis	0	7
9	Implanted tumours	3?	0
10	Immune system and haematological system	5	3
11	Testicular function	8	5
12	Pregnancy and foetal development	9	10

Clearly, the outcomes of these types of experiments continue to be mixed, with no obvious explanation of why under almost identical exposure circumstances different results are obtained in different laboratories. There is a tendency for replication studies to fail to reproduce the RF-related effects in the original study.

Conclusion from in vitro/in vivo research

The AGNIR review covers the period from 2003 to approximately late 2011. The cut-off for the RPS3 Annex 4 review was 2000, so in any revisions of in vitro/in vivo reviews, there will be a need to add to the numbers shown above. There are clearly new topics of research which need consideration and views formed on whether the newer evidence strengthens the summaries presented in RPS3 or otherwise. Although the reports would appear roughly balanced (47% 'effect'; 53% 'no effect'), this does not take into account such considerations as: publication bias; internal consistency; methodological weakness or dosimetric rigour. Most discipline-based reviews conclude thermal effects to be adequate to explain the observed data. Overall, it would seem unlikely that there would be any need to revise the conclusion that the Basic Restrictions should be based on thermal effects. However, despite the growth in the body of knowledge over the last 10 years, the variability in the science supports the rationale for a precautionary approach.

6. Expert Assessment of Human/provocation research

Prof. Rodney Croft

6.1 Structure of Report

This report provides the details of the Author's judgement as to whether the current RF Human Provocation Science indicates that a reconsideration of RPS3 is warranted. It should be noted that the Author's judgement was not based on an analysis of every relevant paper in the literature, as that method was not viable given time constraints. Rather, the report provides the following:

- A consideration of RPS3's conclusions as to the state of RF Human Provocation science at the time of publication of RPS3 (6.4)
- A consideration of the conclusions of major reviews as to the state of RF Human Provocation science (6.5)
- A consideration of whether there are discrepancies between RPS3 and these current major reviews (6.6)
- Where any such discrepancies are identified, a consideration of whether these indicate that a reconsideration of RPS3 is warranted (6.7)
- A consideration of whether there is any further evidence (not considered by RPS3 or the current major reviews), that is relevant to the issue of reconsidering RPS3 (6.8).

6.2 Choice of expert bodies' reviews

As we do not have a classification system that permits one to include/exclude a document as an expert body review, a subjective decision was made that allowed the inclusion of what the Author believed to be the principle recent expert reviews with strong scientific grounding. These are:

- International Commission on Non-Ionizing Radiation Protection, ICNIRP (2009). Exposure to high frequency electromagnetic fields, biological effects and health consequences (100 kHz-300 GHz)
- Scientific Committee on Emerging and Newly Identified Health Risks, SCENIHR (2009). Health Effects of Exposure to EMF.
- Advisory Group on Non-Ionising Radiation, HPA (2012). Health Effects from Radiofrequency Electromagnetic Fields

6.3 Consideration of research not contained in RPS3 or expert bodies' reviews

ARPANSA provided a literature survey covering RF Human Provocation research (see Appendix 5). This list was consulted by the author to determine whether there were any research papers that were not considered in the above Expert Reviews (6.2), and if so, whether they provided sufficient grounds for a reconsideration of RPS3. Further, the author utilised his knowledge of the area more

generally to determine whether there were other research papers (not contained in either the Expert Reviews above or the ARPANSA literature survey), that impact on whether a reconsideration of RPS3 was warranted. Any such research papers were thus included in the author's evaluation of whether a reconsideration of RPS3 was warranted.

Further to this it is noted that there is a Report that has been widely cited in the RF Health debate, the BioInitiative Report (BIR, 2007). The BIR is not included as one of the Reports to be considered in the present Report, primarily because it does not count as an expert body review (rather, it is the opinion of one author only). However, all Human Provocation studies cited in the BIR, as well as the conclusions reached from these, are considered in this Report to determine whether they provide evidence that RPS3 requires reconsideration.

6.4 Consideration of RPS3 conclusions regarding human provocation studies

Unlike the present day, there was only a small body of research pertaining to the effect of RF exposure on humans using provocation designs at the time of RPS3 publication. This was summarised on page 90 of RPS3, where it was concluded that:

- No consistent effects of RF on sleep patterns has been demonstrated
- No effect of RF on pituitary hormone or melatonin production has been demonstrated
- No clinically relevant effects on cardiovascular function have been demonstrated (however, it was not stated whether effects not clinically relevant had been demonstrated).

It may be noted that mention was made of a report of an effect on cardiovascular function, but that as this was methodologically too limited to conclude that an effect of RF had occurred, this was (appropriately) not taken to represent an effect.

Thus no Human Provocation RF effects were reported in RPS3 below the occupational exposure limits, and corresponding to this there was no evidence reported that these limits were inadequate for ensuring safe human exposure.

A limitation of this conclusion may be that the small number of relevant Human Provocation studies raises the possibility that that there are RF health effects within the exposure limits that exist but that were merely not tested. Thus it is important to consider whether subsequent reviews have identified such evidence of harm.

6.5 Consideration of expert bodies' conclusions regarding human provocation studies

International Commission on Non-Ionizing Radiation Protection, ICNIRP (2009)

Due to the bulk of Human Provocation research conducted since RPS3, this review provided an extensive analysis of Human Provocation research (p222-272). The review groups research into the following somewhat arbitrary categories: Nervous System (electrical activity of the brain, auditory

and vestibular system, regional cerebral blood blow, cognitive performance, and subjective symptoms); Endocrine System (melatonin, and pituitary and other hormones); Cardiovascular Function & Thermoregulation (heart rate and blood pressure changes, and cardiovascular responses during thermoregulation). It provides a good coverage of the literature pertaining to these categories, and concludes the following.

Nervous System: It was concluded that there is some evidence for low-level RF (GSM) effects on the electroencephalograph (EEG), in terms of both resting alpha and sleep spindle activity. The qualification ('some evidence') refers to the evidence being strong, but not conclusive at this point, and is differentiated from the remainder of the Human Provocation research domains in that although they also report effects, when considered within the context of the literature as a whole, the remainder do not provide evidence for an effect (due to conflicting findings and methodological issues).

However, the review notes two important caveats. First is that the resting alpha findings have not been corroborated by the results from event related potential (ERP) studies. It is not clear to the Author why this would affect the resting alpha conclusions, as the relation between resting alpha and ERPs is far from clear, and research dedicated to addressing the interaction of RF, resting alpha and ERPs would be required to understand how any such relations might operate (and such research has not been conducted to date). Thus the Author does not believe that the resting alpha/ERP issue affects the tentative conclusion that RF affects resting alpha. The second caveat is that there is no indication that either the resting alpha or sleep spindle changes relate to health. This is important as it means that regardless of the certainty of the resting alpha and sleep spindle findings, there is no indication that this is relevant to RF standards. Thus for these findings to be relevant to RF standards, they would need to be shown to be relevant to health (or at least argued to represent a reasonable possibility for impaired health that has not yet been addressed). The Author is not aware of any such research showing that the alpha or sleep spindle changes relate to health, nor that there is a reasonable possibility that they would. Thus the Author agrees with the ICNIRP 2009 conclusion that these findings do not suggest limitations with ICNIRP Standards, nor correspondingly RPS3.

In terms of the other nervous system endpoints considered in the ICNIRP 2009 review, it is concluded that there is no evidence for any effects of RF. This includes a consideration of subjective symptoms from individuals who believe that they are adversely affected by RF, where although acknowledged that such individuals do indeed suffer ill health, it is concluded that there is strong evidence that this is not related to the RF per se.

Endocrine System: The only endocrine measure that was viewed as 'possibly' affected by RF, was melatonin, whereby one study reported a decrease in saliva melatonin following RF exposure. However, that was treated as very tentative given that a number of other studies have failed to identify such an effect, and thus merely a finding recommended as worthy of confirmation. Thus it was concluded that there is no evidence of effects of RF on the endocrine system, and the Author agrees with this conclusion.

Cardiovascular Function & Thermoregulation: The Review notes that although there have been some reports of RF effects on cardiovascular function, the majority of studies do not report an effect, and given the methodological problems associated with many of the studies, it concludes that there is no evidence that RF affects cardiovascular function.

The Review also considers the effect that RF-related temperature elevation may have on health. It fails to identify any evidence that low-level RF-related temperature changes affect health, only that levels far exceeding RPS3 can have such an effect. It does raise the untested possibility that RF-related temperature changes may affect cognition and thus accident rates, but does not identify any research demonstrating this. The Author views this as very unlikely as experimental research has failed to identify consistent impairment in cognition for core body temperature increases of less than 1 degree C, and there is evidence that RF exposure within RPS3 levels cannot increase core body temperature to this extent (if at all). Thus the Author views RF-related changes to thermoregulation as very unlikely to impact on health.

Conclusion from the ICNIRP Review, 2009

Overall, the Review does not find any Human Provocation evidence that RF levels within RPS3 impact negatively on humans. The Author believes that this is an appropriate conclusion given the available evidence. It further notes that this research is mostly limited to healthy young adults, which raises the possibility that other groups (e.g. children, the elderly and the ill) may not be represented by this research. However no evidence or argument is given suggesting that such populations may be differentially affected by RF. The Author believes that this evidence is sufficient to arrive at an informed conclusion, and that it does not suggest that there is evidence of RF-related harm below RPS3 levels.

Scientific Committee on Emerging and Newly Identified Health Risks, SCENIHR (2009)

SCENIHR 2009 is to be read as an update on the SCENIHR 2007 review, where it takes the 2007 conclusions as a starting point, and then considers whether any research subsequent to that review is relevant to human health. SCENIHR 2009 considers a wide range of Human Provocation research, but as it covers a broader range of frequencies and as it is only considering research subsequent to SCENIHR 2007, there is less detailed discussion of this RF literature than is provided in the ICNIRP 2009 review. The review groups Human Provocation research into the following somewhat arbitrary categories: Symptoms; Nervous System (behaviour and cognition, electrophysiological measurements, sensory related functions); & Miscellaneous Human. Although it is less clear than in the ICNIRP 2009 review which studies have been included in its deliberation, it is implied in the SCENIHR 2009 review that all relevant research since SCENIHR 2007 has been considered, and as the two contemporaneous Reviews' conclusions are similar, this provides some support for the view that it did in fact consider the appropriate literature. The Author believes that the SCENIHR 2009 review does arrive at appropriate conclusions given the literature at the time, where it concludes the following.

Symptoms: SCENIHR 2007 concluded that there was no evidence that individuals experienced symptoms as a result of RF, nor that they were able to detect the presence of RF. Extending from this, SCENIHR 2009 notes that there is a substantial difference in the results from double-blind versus open exposures in terms of symptoms, with only open exposure methods finding symptoms to be

related to exposure status. They conclude that this provides evidence for the nocebo effect, rather than RF playing a causal role in symptom provocation. Thus they conclude that there is currently no evidence that RF (within RPS3 levels) affects symptoms or the perception of exposure, within either healthy individuals or those reporting sensitivity to RF. This is consistent with the ICNIRP 2009 review conclusions, and the Author believes that this does represent strong evidence against the thesis that low level RF can cause the symptoms that have been reported by those who believe themselves to be sensitive to RF emissions.

Nervous System: SCENIHR 2007 concluded that there was no consistent evidence that low level RF affects behaviour and cognition (where cognition is measured behaviourally) or sensory processes, but that there was some evidence of RF-related changes to electrophysiological endpoints. SCENIHR 2009 concludes that subsequent research does not alter its conclusions in relation to cognition or sensory processes, however it strengthens its conclusions in relation to electrophysiological endpoints, noting that recent research indicates that RF does affect resting and sleep EEG (albeit noting the lack of demonstrable relevance of this to health). All of these conclusions are consistent with those of ICRNIRP 2009.

Miscellaneous Human: SCENIHR 2007 concluded that there was no evidence of other 'miscellaneous' health effects due to RF, and SCENIHR 2009 concluded that as no further research has been conducted, the 2007 conclusion is still valid.

Conclusion from SCENIHR 2009

Overall the SCENIHR 2009 conclusions are very similar to those of ICNIRP 2009. The Review does not find any Human Provocation evidence that RF levels within RPS3 impact negatively on humans. In particular, it finds that there is currently no evidence that RF (within RPS3 levels) affects symptoms or the perception of exposure, within either healthy individuals or those reporting sensitivity to RF, or behaviour, behavioural measures of cognition, nor sensory processes, but that there was some evidence of RF-related changes to electrophysiological endpoints that did not relate to health. The Author believes that this is an appropriate conclusion given the available evidence.

Advisory Group on Non-Ionising Radiation, AGNIR (2012)

AGNIR considers a wide range of Human Provocation research in their review that was published since their previous review (AGNIR, 2003), and groups Human Provocation research into the following somewhat arbitrary categories: Neurocognitive Effects (cognitive and performance studies, EEG and ERP, other neurophysiological studies, and auditory and vestibular studies); Symptoms; and Other (Non-Cancer) Studies (cardiovascular function). It provides a good coverage of the literature pertaining to these categories (reported in pages 205-264), and concludes the following.

Neurocognitive Effects: There are a large number of cognitive and performance studies that argue against the possibility that this domain is affected by RF exposure. Similarly, it is concluded that there is no evidence of an effect of RF on auditory and vestibular function. AGNIR 2012 also notes that there is a large number of resting and sleep EEG studies that report effects of RF, however, they argue that this body of research is not yet convincing, and that even if it was shown to occur, that there is no evidence that this relates to health. Thus its conclusion regarding this is similar to ICNIRP 2009 and SCENIHR 2009 in terms of its relevance to current RF standards (and thus RPS3), but less committal than both of these in terms of whether the reports of EEG effects are accurate. Although the Author's view regarding EEG are more closely aligned with that of ICNIRP 2009 and SCENHIR 2009, he agrees with the most relevant point of AGNIR 2012 (which concurs with that of ICNIRP and SCENHIR 2009), which is that there is no evidence that these results are relevant to current RF standards (and thus RPS3), and thus that they do not provide any justification for a reconsideration of RPS3.

Further, due to the greater body of recent research pertaining to the above effects on children and adolescents, unlike ICNIRP 2009 and SCENIHR 2009, AGNIR was able to consider whether there was any evidence that the 'developing brain' was more sensitive than the healthy adult brain to RF. AGNIR concluded that there was no evidence that it was, but noted that there is still a 'relative' paucity of research to base this conclusion on. The Author agrees with both of these points, and as such concludes that there is no data that shows that RPS3 may not be cautious enough when considering children and adolescents.

Symptoms: AGNIR concludes that there is now a substantial body of Human Provocation research pertaining to symptoms and exposure status, and that it does not provide evidence that either healthy controls or those reporting sensitivity to RF, are capable of detecting the presence of RF, or that they experience symptoms due to RF. Given the difference between results from double blind and open trials, they also conclude that the evidence suggests the possibility of a nocebo effect, rather than RF playing a causal role in symptoms. Thus they conclude that there is currently no evidence that RF (within RPS3 levels) affects symptoms or the perception of exposure, within either healthy individuals or those reporting sensitivity to RF. This is consistent with both the ICNIRP 2009 and SCENIHR 2009 conclusions, and the Author believes that this does represent strong evidence against the view that low level RF can cause the symptoms that have been reported by those who believe themselves to be sensitive to RF emissions.

Other (Non-Cancer) Studies: AGNIR concludes that there are number of well conducted studies addressing the issue of whether RF affects heart function, and that these provide strong evidence that there are no such effects. They note that one study has shown a likely increase in microperfusion of the ear due to RF, and that this is likely due to low level heating, but also note that there is no evidence that this relates to health. Thus they conclude that there is no evidence from cardiovascular research that RF affects health. This is consistent with ICNIRP 2009 and SCENIHR 2009, and the Author agrees with this conclusion and thus that this research domain does not provide evidence of inadequacies in RPS3.

Conclusion from AGNIR 2012

Overall the AGNIR conclusions are very similar to those of ICNIRP 2009 and SCENIHR 2009. The Review does not find any Human Provocation evidence that RF levels within RPS3 impact negatively on humans. In particular, it concludes that that there is no evidence that cognitive and performance measures of human function are affected by low level RF exposure (with a caveat being that there is uncertainty concerning EEG results, which are not relevant to health), that there is no evidence that either healthy controls or those reporting sensitivity to RF are capable of detecting the presence of RF or that they experience symptoms due to RF, and that there is no evidence that heart function is affected by low level RF exposure. The Author believes that this is an appropriate conclusion given the available evidence.

6.6 Discrepancies between RPS3 and recent expert bodies' conclusions

Only minor discrepancies were identified between the ICNIRP 2009, SCENIHR 2009 and AGNIR 2012 reviews. As described above, the most important of these is that ICNIRP 2009 and SCENIHR 2009 view the resting and sleep EEG findings as more conclusively demonstrated than does AGNIR 2012.

6.7 Do any discrepancies indicate a need for RPS3 reconsideration?

The only discrepancies between the three reviews considered were minor, and none suggest that there is any evidence of health-related effects within RPS3 levels. For example, although the reviews differ slightly in terms of how conclusive the demonstration of RF-related EEG effects is, they each conclude that there is no evidence that such an effect would be relevant to health. Thus the three reviews are in accord in concluding that there is no evidence that RPS3 levels can result in health effects.

6.8 Is there any missing evidence that impacts on conclusions reached in 6.7?

ARPANSA's Literature Review

The Author has considered the ARPANSA literature review, which is more inclusive than those of the three Reviews described above, and does not believe that it contains any research that invalidates the conclusions of those Reviews.

The Author's knowledge of the literature

The Author, being heavily involved in RF/Health research, has also considered whether there is any research beyond that described in the three Reviews and the ARPANSA Literature Review that may alter the conclusion that there is no evidence that RF exposure within RPS3 levels results in health effects. The Author is not aware of any such omitted research.

The BioIniative Report 2007 (BIR)

There is a clear discrepancy between the conclusions of the BIR and those of ICNIRP 2009, SCENIHR 2009 and AGNIR 2012, particularly in terms of conclusions reached from research concerning RF and brain tumours. However, in terms of human provocation research, essentially the same conclusions are reached as those from the Reviews considered above.

The BIR contains only one section on human provocation research (Section 9), which is authored by only one person (Henry Lai). Consistent with ICNIRP 2009 and SCENIHR 2009, Lai concludes that there is evidence that low level RF affects the human EEG, but consistent with these and AGNIR 2012 he also concludes that there is no human provocation research supporting the view that this represents harm. Beyond these points, he does not argue for evidence of any negative effect from low level RF on humans. Consistent with this, Section 1 of the BIR (authored by Cindy Sage), which states that it provides a summary of the various sections of the BIR, does not conclude that there is human provocation research that has demonstrated any negative health consequences from low level RF.

Thus although there are claims in the BIR that do relate to health, there is nothing concerning human provocation research that importantly contradicts the conclusions reached by ICNIRP 2009, SCENIHR 2009 or AGNIR 2012. The BIR thus does not provide any evidence that the current RPS3 limits may result in negative health consequences.

Conclusion from human provocation research

It is concluded that there is no human provocation evidence from ICNIRP 2009, SCENIHR 2009 or AGNIR 2012 that raises any doubt about the adequacy of the limits described in RPS3. Further, neither the BioInitiative Report (2007) nor the ARPANSA literature review provide any further evidence that mitigates against that conclusion, and to the Author's knowledge there is no additional human provocation research that demonstrates that the RPS3 limits are inadequate for protecting humans.

Thus the Author concludes that based on the human provocation research, there is no evidence of a need for the reconsideration of the exposure limits in RPS3.

7. Expert Assessment of Dosimetry

Prof. Andrew Wood

This dosimetry section examines the advances in computation of the deposition of radiofrequency energy within human tissue. This confirms that the RPS3 Basic Restrictions and Reference Levels continue to provide high levels of protection against the known thermal effects. It is noted that for some frequency ranges and body sizes, that while there are no likely health impacts, more sophisticated dosimetric calculations indicate that the Reference Levels may not provide as large a margin of protection as was originally thought.

The fundamental restrictions over most of the frequency range of current exposure standards apply to the rate of deposition of radiofrequency energy within human tissue (specific absorption rate, SAR). Since this quantity is relatively inaccessible, both in experimental situations and in practical compliance checking, measurements of the electric and magnetic fields (or equivalent flux of electromagnetic energy) external to the body are generally used to estimate, or infer, the SAR level.

For environmental exposures, where the incident radiation is relatively uniform, the exposure standards place limits on whole-body-average SAR (SARWB) which adds to the total amount of thermal energy the body must dissipate. While the human body has well developed thermal regulatory systems and can cope with large additional thermal inputs without undue temperature increases, these mechanisms have limitations and place a load on body systems that can lead to impacts including deterioration of work performance and other undesirable effects.

For exposures from transmitting equipment used very close to the body, or specialised occupational situations, the deposition of energy within the body can be very non-uniform and localised SAR and local temperature rises need to be controlled. Current standards permit localised SAR, as commonly defined as the average of 10 g of tissue (SAR10g) to exceed whole-body-average SAR by factors of 20 – 25, based on estimates that this will restrict localised temperature rises to less than 1° C.

The development over the last decade of more realistic numerical models of the human body (phantoms), derived modern imaging technologies, has greatly improved the reliability of the estimates of SARWB and SAR10g for given exposure situations and confirmed the conservatism of current Reference Levels in most circumstances. Phantoms have now been developed for a variety of body sizes (including newborn infants) and these use better estimates of the electrical properties of human tissue. These improved models allow better understanding of both the experimental studies that led to the formulation of current Basic Restrictions (SARWB and SAR10g) and of the derivation of limits on external fields (Reference Levels) that may be used to ensure compliance with the Basic Restrictions. Of special interest has been the examination of the assumptions made in deriving the values in the current standards for a wider range of body size, including, particularly, children.

Using these improved models, evidence is accumulating that the current Reference Levels are not as conservatively formulated for short-statured adults, or young children, including babies, as was earlier thought. In addition, the margin of conservatism between the Basic Restrictions (BRs) and situations in which an increase of regional body temperature rises above 1° C due to RF exposure

may also be less than previously estimated. The principal studies indicating possible shortcomings in the ICNIRP-derived Reference Levels relative to the Basic Restrictions are summarised below.

In a study in which thermal and electromagnetic models were combined, Bernardi et al., (2003) concluded that, in comparing BRs with thresholds for 'thermal damage', the safety factor for determining the Whole Body Specific Absorption Rate (SARWB) limit 'is reduced from 50 to 10 when local temperature increases are considered'. For example, at 40 MHz, the models predict increases of temperature in the ankle of 0.72° C for a 10g SAR of 3 W/kg with a plane wave power flux density (PFD) of 2 W/m^2. This would imply that, at the 4W/kg limb limit for the public, the temperature rise would be around 1°C. Since a 6° - 8° rise is the threshold for damage, the safety margin for this limb limit is small. At the occupational limit of 20 W/kg the safety margin is virtually non-existent. It should be noted that 40 MHz represents a resonant condition and similar temperature rises are not expected over the wider frequency range. In the region 1 – 10 GHz, Laakso (2009) has also noted that a SAR10g of 10 W/kg occurring in the brain (the occupational limit) can produce temperature rises of over 1°C, but the paper notes that this could be an over-estimation.

Conil et al. (2008) report a large variability in SARWB when considering six different anthropomorphic models (representing differing gender and ethnicity), with up to a 40% deviation from the mean. The study also reported that for the 5-year and 9-year old child models the SARWB was exceeded in the range 1.5 – 3 GHz for incident power flux densities at the ICNIRP limits of 10 W/m^2 above 2 GHz.

The possibility of exceeding the current Basic Restriction limits for exposures that meet current Restriction Levels has also been reported by the Health Protection Agency/University of Florida group (Dimbylow & Bolch, 2007; Dimbylow et al., 2010). They reported situations above 1.5 GHz with PFD levels below the Reference Levels producing SARWB up to 50% in excess of Basic Restriction limits and also marginally in excess at the respective resonant frequencies for children below 4 years of age. A PFD of around 6.63 W/m^2 (50 V/m) is suggested as being more appropriate above 1 GHz.

Dimbylow et al., (2010) reported that the current Reference Levels failed to provide adequate protection for newborns at resonance for certain polarisations (orientations of the electric field) in the region of 200 MHz, suggestive of a need to lower the PFD limits in this range. Further, the study of Uusitupa et al. (2010) has shown that even for small adults, certain polarisations in incident plane waves can lead to exceeding the SARWB limit, again suggestive of the need to lower RLs in the range 2 – 5 GHz. Recent work by Lee and Choi (2012) confirms the need to lower RLs in this range and also in the range 20 – 200 MHz.

Overall, the research cited above indicates that meeting current Reference Levels may not guarantee meeting of Basic Restrictions over all body sizes in some frequency ranges and that the safety margins provided by current Reference Levels may be lower than intended. The localised SAR in limbs may also lead to temperature rises larger than previously thought and the acceptability of this needs to be reviewed.

In addition to the work cited so far, there is a growing literature of SAR values associated with the RF component of MRI, including the effects of body morphology. This literature tends not to be reflected in RF dosimetry reviews and needs to be considered.

Conclusion from Dosimetry

While recent advances in numerical dosimetry have confirmed the conservatism of current exposure limits in most circumstances, the inclusion of a wider range of body sizes has produced strengthening evidence that the Reference Levels may not be providing the intended safety margins at some frequency ranges for certain body sizes. Further, there is also the question of whether the Basic Restrictions continue to be an accurate indicator of local rise in temperature, particularly in the limbs under resonant conditions and hence the degree of protection against protein denaturation and other adverse thermal effects. The Rationale and other sections of RPS3 could be revised to reflect the current state of knowledge in this area.

8. Expert Assessment of Epidemiology

Dr Geza Benke

When dealing with incidence and distribution of disease in human populations, if the dose-response relationship is weak then epidemiology is limited in its usefulness. The epidemiology regarding RF exposure can be dichotomized into carcinogenic effects and non-carcinogenic effects. The recent IARC review (Baan et al., 2011) perhaps best illustrates the current position on the carcinogenic effects of RF with the conclusion that there is limited evidence in humans, and RF was classified as 'possibly carcinogenic to humans'(Group 2B). There have been over a hundred epidemiological publications since the standard was published regarding cancer, other outcomes and RF exposure.

Despite many international collaborative efforts (Interphone, 2010), a clear dose-response relationship for the most important of the carcinogenic effects, brain cancer, has not been described. The lack of any consistent dose-response relationship is primarily due to the inconsistent results of the many case-control studies reported in recent years. Case-control studies suffer from many biases and confounders, so results from cohorts studies are considered more reliable. However, since the review of the epidemiological literature and publication of the current standard there have not been many cohort studies published. The heavily criticised Danish cohort study has been the largest and most extensive of these, but has not shown an association between mobile phone exposure and a range of cancers (Frei, 2011).

In addition to the inconsistent descriptive study results, there have not been any significant increases in the population rates for brain cancer in recent years (Larjavarra et al., 2011). It is reasonable to contend that it may yet be too early, given the long latency period for brain cancer, for an increase to be observed. However, the world population exposure has increased exponentially since the late 1990s and if RF exposure from mobile phones is carcinogenic then increased population rates should be observed in the very near future.

The findings for non-carcinogenic effects have mirrored those for the carcinogenic effects. For non-thermal exposure levels, there has been inconsistent evidence for cognitive function effects. Studies investigating possible cognitive function effects have not been able to describe a dose-response relationship and so have not been able to contribute to meaningful consideration of adverse effects.

The results of the environmental studies since the publication of the standard for broadcast transmitters and mobile phone base stations have also be inconsistent. Many of these studies were ecological or cross-sectional in design and were at best hypothesis generating. Limitations regarding the methods and interpretation of results have been well described elsewhere (ICNIRP, 2009).

Conclusion from Epidemiology

Although the epidemiology in the past decade has improved our understanding of the limitations of exposure assessment and likely extent of RF exposure to humans, it has not progressed with any dose-response relationships regarding carcinogenic and non-carcinogenic effects which would warrant significant changes to the current Standard.

9. Epidemiology – Literature Review

Dr Ken Karipidis

9.1 Introduction

Since 2000 epidemiological research has grown rapidly and in particular studies on mobile phones and cancer. We conducted a review of epidemiological studies published from January 2000 till August 2012 on RF and health.

All studies found during the literature search outlined in 2.1 were included, whether they have been peer-reviewed or not. Non-English-language papers were included in the review by extracting information from English abstracts. When abstracts of non-English publications were not available, the papers were still cited. Papers included, were all types of epidemiological studies (cohort, case-control, cross-sectional, ecological) as well as meta- and pooled analyses. Reviews, editorials, methodological papers (exploring exposure assessment, bias, confounding etc), case reports, letters or comments were not generally included although some of these were used in preparing this summary.

The papers found were classified into three main categories according to the source of the exposure, namely: (a) occupational exposure, (b) environmental exposure from transmitters, and (c) personal exposure from wireless devices.

9.2 Occupational exposure

The epidemiological studies on occupational exposure that have been published since 2000 have looked at a variety of health outcomes. However, nearly half of the studies are devoted to cancer outcomes.

9.2.1 Cancer

9.2.1.1 Cohort studies investigating a range of cancers

There were three large cohort studies, investigating a wide range of cancer outcomes in groups with potential RF exposure. The study by Morgan et al. (2000), conducted on Motorola employees in the US, was reviewed in the epidemiological annex of the 2002 ARPANSA Standard (ARPANSA, 2002). The study examined all major causes of mortality, with brain cancers, lymphomas, and leukaemias as a priori outcomes of interest. The study results did not suggest any general increased mortality risk, and showed no evidence of an increase in any specific cancers. Groves et al. (2002) updated an earlier study on mortality related to RF exposure (from radar) in a cohort of Korean War US navy technicians, as compared to other veterans deemed to be in low-exposure jobs. The results of this study also found that in general RF exposure had little effect on mortality due to cancer. However there was one possible exception with an increased risk of nonlymphocytic leukaemia in radar-exposed navy veterans restricted to only one of three highly exposed occupations (aviation electronics technicians). In the most recent cohort study, Degrave et al. (2009) investigated cause

specific mortality in Belgian military personnel who served in anti-aircraft radar units. The authors reported an increase in hemolymphatic cancers, although the results were based on small numbers.

There were a further three cohort studies investigating occupational RF exposure and cancer however these studies were of lower quality. Richter et al. (2000) reported increased cancer morbidity amongst radar technicians however the cohort included only 25 workers. In a study of the whole male population of military career personnel in the Polish army, Szmigielski et al. (2001) reported significantly higher morbidity rates in the group classified as exposed to RF fields for various cancers including brain tumours and leukaemias. However this study has been heavily criticized for its methodological inadequacies, for example, the study used more sources of exposure information for cancer cases than for non-cancer subjects and was analysed improperly (Ahlbom et al., 2004). Another cohort study by Soleneva et al. (2004) reported no overall mortality risk amongst TV workers but showed increased mortality risk for malignancies of some locations; however this study was published in Russian and methodological details could not be discerned from the English abstract.

9.2.1.2 Case-control studies investigating specific cancers

There were several case-control studies of specific cancer sites, investigating occupational RF exposure. De Roos et al. (2001) found no statistically significant association between parental occupational exposures to RF and the incidence of neuroblastoma in offspring. In the same year Stang et al. (2001) reported an increased risk of ocular melanoma in subjects with self-reported occupational exposure to RF and Fabbro-Peray et al. (2001) reported excess risk of non-Hodgkin lymphoma among radio operators. Baumgardt-Elms et al. (2002) found no association between people that worked in close proximity to RF emitters and testicular cancer. In a nested case-control study Kliukiene et al. (2003) found no statistically significant excess breast cancer risk among female radio and telegraph operators. In two fairly recent studies, Karipidis and co-workers showed no significant associations between RF exposure (assessed using a job-exposure matrix) and glioma and non-Hodgkin lymphoma (NHL) (Karipidis et al., 2007a, 2007b). Berg et al. (2006) and Samkange-Zeeb et al. (2010) used subjects that participated in the German part of the INTERPHONE project (which will be discussed later) to assess whether occupational exposure was associated with brain tumour; no significant association was found. Similarly, Baldi et al. (2011) found no association between occupational RF exposure and brain tumours.

9.2.1.3 Occupational studies based on job-title alone

There were also 3 studies analysing collected data sets on cancer incidence or mortality, in which risks of cancer were assessed in relation to job title with a presumed exposure to RF but also other physical or chemical agents. Ballard et al. (2000) investigated cancer incidence and mortality among flight personnel by conducting a meta-analysis of cohort studies. The authors reported an increased risk associated with flight personnel for several types of cancer. In investigating non-Hodgkin lymphoma and occupation, Cano and Polan (2001) reported excess risk among telecommunications workers. However, the lack of individual information on level and duration of exposure weakens any causal inferences derived from these studies.

Conclusion from occupational studies on cancer

In general, the studies investigating occupational exposure to RF and cancer since 2000 continue to show inconsistent results and have not greatly improved on the methodological problems of older studies. A major limitation in the occupational studies continues to be poor exposure assessment. None of the three large cohort studies improved on the information collected on exposure from older cohort studies. Some of the more recent case-control studies have improved on exposure assessment by using sophisticated job-exposure matrices however exposure misclassification is not eliminated. The continuing issue of inadequate exposure assessment combined with other methodological limitations inhibits any firm conclusions from the occupational cancer studies to date.

9.2.2 Other (non-cancer) health outcomes

Occupational studies have also investigated a variety of outcomes other than cancer. In a retrospective cohort, Degrave et al. (2005) found no increase in all-cause mortality in military personnel who were in close contact with radar equipment. In an extended follow up of the same cohort, Degrave et al. (2009) found no increase in mortality from other specific diseases[2].

9.2.2.1 Reproductive effects

Several studies since 2000 have investigated a wide range of potential reproductive consequences of occupational RF exposure, although results have been largely inconsistent. In a cross-sectional study, Grajewski et al. (2000) reported minor semen quality and hormonal differences between RF dielectric heater operators and an unexposed control group. In a case-control study of female physiotherapists, Lerman et al. (2001) reported an association between exposure to RF short-waves and harmful effects on pregnancy outcomes, specifically low birth weight. In contrast, in a cross-sectional study, Cromie et al. (2002) found reduced incidence of congenital malformations and miscarriage in physiotherapists.

Several studies have investigated reproductive outcomes in people working with radio communications equipment, primarily in the military. In a case-control study investigating male infertility factors in the French military, Velez de la Calle (2001) found no significant association with RF exposure. A series of Chinese cross-sectional studies reported effects on male fertility and sexual function in radar operators (Liu et al., 2003; Ding et al., 2004; Yan, 2007; Ye, 2007). There have been four Norwegian studies conducted on naval personnel; three cross-sectional studies included Mageroy et al. (2006) who reported a higher risk of congenital anomalies in the offspring of personnel who served aboard a missile torpedo boat and Baste et al. (2008) and Mollerlokken and Moen (2008) who showed an association between working with RF equipment and radar and reduced fertility. The fourth study was a cohort of Navy servicemen that showed an association with serving aboard fast patrol boats with an increased RF exposure and adverse pregnancy outcomes (Baste et al., 2012).

[2] There was an increase in hemolymphatic cancers as mentioned earlier.

Finally, two studies have examined reproductive outcomes in the general working population; in a retrospective cohort study, Mjoen et al. (2006) found no link between paternal occupational exposure to RF and risk of adverse pregnancy outcomes, and in a case-control study investigating various physical or chemical occupational exposures and semen quality, De Fleurian et al. (2009) did not find an association with RF fields. Generally, possible adverse effects of occupational RF exposure and reproductive outcomes have remained unsubstantiated suffering from similar methodological problems as in the cancer studies where exposure assessment limitations prevent any firm conclusions. These results do not change the conclusions of the pre 2000 studies which were mainly based on investigations with physiotherapists and military personnel and also showed little consistency (ARPANSA, 2002; Ahlbom, 2004).

9.2.2.2 Cardiovascular effects

A number of mainly cross-sectional studies have investigated cardiovascular effects related to occupational RF exposure. Tikhonova in two separate studies reported a higher risk of cardiovascular disease in personnel working at a civilian aircraft radar-tracking system (Tikhonova, 2003; Tikhonova and Rubtsova, 2004). Wilen et al. (2004) reported lower heart rate and more episodes of bradycardia in RF welding operators compared to controls. The same authors reported changes in heart rate variability associated with RF exposure in a study using the same subjects (Wilen et al., 2007). Bortkiewicz et al. (2003) reported changes in the circulatory system of radio and TV broadcast workers and also found a significant relationship between blood pressure and neurovegetative regulation disorders and exposure parameters. Investigating a similar occupational group Vangelova et al. (2006) found that blood pressure and cholesterol were higher in radio and TV station operators compared to controls. Higher cholesterol levels were also reported for physiotherapy staff compared to controls by Israel and Ivanova (2007).

Although the above studies investigating cardiovascular effects have shown positive associations with occupational RF exposure, these studies were cross-sectional which by themselves cannot infer causation. The three large cohort studies by Morgan et al. (2000), Groves et al. (2002) and Degrave et al. (2009) mentioned earlier reported no association between occupational RF exposure and cardiovascular mortality. In addition a smaller cohort study by Solenova et al. (2004) also exhibited lower mortality rates associated with cardiovascular disease among TV workers.

9.2.2.3 Genetic effects

Since 2000 a small number of cross-sectional studies of cytogenetic biomonitoring in workers exposed to RF have been published (Lalic, 2001, radio-relay station workers; Magdy, 2002, engineers and air traffic controllers; Maes, 2006, radio engineers; Garaj-Vrhovac, 2009, 2010, radar workers). The studies on genetic effects have been reviewed by Verschaeve (2009). All of these studies show a relationship between occupational exposure to RF and genetic damage (e.g. chromosomal aberrations). However all of these studies have numerous methodological limitations including poor study design, lack of exposure assessment and limitations due to confounding and bias.

9.2.2.4 Other (non-cancer) effects

Pak et al. (2001) reported haematological and cytochemical effects in workers servicing radio communications equipment. Wilen et al. (2004) did not find a significant difference between RF operators and controls in the prevalence of subjective symptoms such as fatigue, headaches, and warmth sensations in the hands. In two separate studies, Vangelova et al. did not find any variation in the melatonin levels of TV station operators, although there was a change in the excretion rates of stress hormones when compared to controls (Vangelova et al., 2002; Vangelova et al., 2005). In another study conducted on people working in broadcasting stations, Oktay et al. (2004) reported higher hearing thresholds for these workers. A study investigating various health parameters by Yuan et al. (2004) found that low intensity VHF fields can decrease the nervous system function in occupationally exposed personnel and induce increase in specific enzymes and immunoglobulins. Tuschl et al. (2000) reported no substantial overall suppressive effect in immune parameters in workers using induction heaters (most of which included frequencies in the very low-frequency, VLF, range of 3–30 kHz), compared with controls.

Although there were some pre 2000 studies investigating possible associations between occupational RF and cataracts there were no post 2000 studies published for this health outcome.

Conclusion from occupational studies and other (non-cancer) health effects

Overall the literature regarding occupational RF since 2000 provides little evidence of an association with other (non-cancer) health effects.

9.3 Environmental exposure from transmitters

A variety of epidemiological studies investigating environmental exposure from transmitters (including radio, television, microwave, and mobile telephone communications) and health have been published since 2000.

9.3.1 Cancer

9.3.1.1 Broadcast transmitters

Some of the studies since 2000 have investigated the incidence of cancer near radio or TV transmitters. Cooper et al. (2001) updated the earlier studies by Dolk and co-workers of cancer incidence around the Sutton Mast radio and TV transmitters in the UK (Dolk, 1997a & 1997b). They used more recent cancer data to re-analyze cancer incidence around the transmitters and found no significant associations. However, in a similar study, Michelozzi et al. (2002) reported excess childhood leukemia in a population living near the high-power radio transmitters of 'Vatican Radio'. Similarly, Ha and co-workers, in two separate studies investigating cancer incidence within 2km of AM radio transmitters showed increases in some cancers, including childhood leukaemia, but not other cancers (Ha et al., 2003; Park et al., 2004). A correlation between melanoma incidence and the number of FM transmitters was reported by Hallberg et al. in three separate (but very similar) studies

(Hallberg et al., 2002, 2004, 2005). Hocking and Gordon (2003) updated an earlier study (Hocking et al., 1996) to show an association between residential proximity to TV transmitters and decreased survival among cases of childhood leukeamia in North Sydney, Australia. An update of an earlier study on tumour data for residential areas in the vicinity of the Lookout Mountain transmitters in the US found a persistent elevation of brain tumours (CDPH, 1999, 2004). Finally Preece et al. (2007) found no excess cancer in three villages in the vicinity of military antennas. Most of the above studies were ecological in design[3] , lacking any information on individual subjects so it is difficult to draw firm conclusions from these results (e.g. individual RF exposures are not necessarily related to distance).

There have also been three case-control studies that have investigated broadcast transmitters and cancer. Ha et al. (2007) reported an increased leukaemia risk for children living within 2km of AM broadcast transmitters; there was no excess risk for brain cancer. However, two recent case control studies (Merzenich et al., 2008; Schmiedel et al., 2009) showed no elevated risks of childhood leukaemia associated with living within 2km of radio and TV transmitters.

9.3.1.2 Mobile phone base stations

A limited number of studies have investigated exposure from mobile phone base stations (no studies were reported prior to 2000). Four ecological studies reported higher cancer incidence in the vicinity of base stations (Eger et al., 2004, 2009; Wolf and Wolf, 2004; Dode et al., 2011). However two other ecological studies found no elevated cancer incidence in municipalities with mobile phone base stations (Meyer et al., 2006; Stewart et al., 2012). In a cross-sectional study, Yildirim et al. (2010) reported no difference in measures of carcinogenesis (micronucleus frequency and chromosomal aberrations) between people living close to base stations and healthy controls. It must be noted that a study by Oberfeld (2008)[4] showing a significant cancer incidence with regard to timing and location in the area around a base station was withdrawn amidst reports that the base station cited in the paper did not in fact exist[5]. In a review of base stations and health consequences, Valberg et al. (2007) noted that given the random nature of the distribution of cancers in the population, it is not surprising, statistically, that cancer clusters should appear. Valberg et al. also pointed out that given the ubiquity of base stations in the community, one would expect that a base station being near existing cancer clusters is a likely occurrence.

The most recent work on base stations and cancer has been three case control studies. Spinelli et al. (2010) found that residing less than 500 m to base stations was associated with a statistically significant decreased risk for brain tumour. In a large case control study Elliott et al. (2010) reported no association between risk of early childhood cancers and estimates of the mother's exposure to mobile phone base stations during pregnancy. Finally in a study that investigated both base stations and broadcast transmitters Atzmon et al. (2011) found no apparent trend in overall cancer risk to be associated with proximity to any type of transmitters.

[3] The study by Preece et al. (2007) was cross-sectional design.
[4] http://www.powerwatch.org.uk/news/20080325_oberfeld_study.pdf.
[5] http://www.fmk.at/Medien/FMK-Presseaussendungen/2009-(1)/FMK-Krammer--Mobilfunk-ist-in-Osterreich-Trumpf?lang=en-US.

Conclusion from studies investigating transmitters and cancer

Overall, the post 2000 epidemiological research on environmental RF exposure from transmitters and cancer does not provide adequate evidence for a possible association and has not improved on the inconsistencies of the pre 2000 studies. The studies are hampered by many methodological limitations such as diverse exposure sources, poorly estimated population exposures, and selective investigation in response to cluster concerns.

9.3.2 Other (non-cancer) health outcomes

9.3.2.1 Mobile phone base stations

There were no studies prior to 2000 that investigated environmental exposure from transmitters and outcomes other than cancer. However, since 2000, a number of cross-sectional studies on the occurrence of subjective symptoms and well-being in relation to RF exposure from mobile phone base-stations have been published. Several of these have reported a range of symptoms related to well-being of people living in the vicinity of base stations (Santini et al., 2002a, 2003[6] ; Navarro et al., 2003; Oberfeld et al., 2004[7] ; Hutter et al., 2006; Gadzicka et al., 2006; Abdel-Rassoul et al., 2007; Blettner et al., 2009; Eger and Jahn, 2010; Kato and Johansson, 2012). However, there have also been studies that have not found an association between living close to base stations and subjective symptoms (Eltiti et al., 2007[8] ; Thomas et al., 2008a, Berg-Beckhoff et al., 2009; Kuhnlein et al., 2009; Breckenkamp et al., 2010; Mohler et al., 2010, 2012; Roosli et al., 2010; Baliatsas et al., 2011; Frei et al., 2012). A noteworthy study by Augner et al. (2009) found that people living within 100m of a base station (self-proclaimed) were more psychologically strained than others whilst there was no difference in EMF-related health concern. A more recent study reported a correlation between subjective symptoms and residential distance to base stations but no correlation with measured electric field strength (Bortkiewicz et al., 2012). The ICNIRP (2009) review suggested that studies of symptoms and well-being find a higher prevalence of symptoms among people who are concerned about exposure from base-stations, whereas there is little evidence for an association between measured RF levels and the studied outcomes.

There were only two studies on mobile phone base stations which investigated effects other than subjective symptoms. In a cross-sectional study, Buchner and Eger (2011) reported modification of clinically important neurotransmitters in participants living close to a base station. In another cross-sectional study, Eskander et al. (2012) reported effects on the hormone levels of people living within 500 m of a base station.

[6] The 2002a and 2003 papers by Santini present the same data.
[7] The study by Oberfeld et al. (2004) is a reanalysis of the results by Navarro et al. (2003).
[8] The study by Eltiti et al. (2007) investigated both mobile phone and broadcast antennas.

9.3.2.2 Broadcast transmitters

There have been some cross-sectional studies that have investigated broadcast transmitters and outcomes other than cancer (none pre 2000). A series of three Italian studies reported immune system effects (reduced cytotoxic activity) in women that lived in the vicinity of radio and TV antennas compared to a control group (Del Signore et al., 2000; Boscolo et al., 2001, 2006). Abelin et al. (2005) showed sleep disturbances in people living in the vicinity of a short-wave broadcast transmitter. In a follow up study, Altepeter et al. (2006) showed that sleep quality improved once the short-wave transmitter was shut down, however the authors noted that since blinding of exposure was not possible this may have affected the outcome. More recently Clark et al. (2007) reported increased estrogen metabolite excretions among postmenopausal women residing near radio and television broadcasting transmitters. Preece et al. (2007) reported no association between specific illnesses and military antennas; although there was heightened risk perception and a considerable excess of migraine, headache and dizziness, which the authors attributed to the visibility of the transmitters and not the RF. Finally in a large study Mohler et al. (2010) showed impairment of subjective sleep quality due to exposure from various RF sources including broadcast antennas.

9.3.2.3 All transmitters

A recent meta-analysis of epidemiological studies investigating subjective symptoms included all types of transmitters (Baliatsas, 2012). The authors reported no association between RF transmitters and subjective symptoms.

Conclusion from studies investigating transmitters and other (non-cancer) outcomes

Overall, the cross-sectional studies on environmental RF exposure from transmitters have not produced convincing evidence for an association with subjective symptoms or other (non-cancer) health effects. There are a number of methodological limitations in cross-sectional studies including poor exposure assessment and reporting bias related to the effects studied.

9.4 Personal exposure from wireless devices

This category mainly focuses on exposure from mobile phones but also includes cordless phones and other wireless devices. Although published research on mobile phones and health was limited prior to 2000 the rate of publication has increased in the last decade. The vast majority of epidemiological studies published since 2000 have focussed on mobile phone exposure.

9.4.1 Cancer

As with occupational exposure and environmental exposure from transmitters, the majority of studies involving mobile phones have concentrated on cancer outcomes and in particular brain tumours.

9.4.1.1 Cohort studies investigating a range of cancers

There has been one large cohort study with three follow up analyses investigating mobile phone use and a variety of cancers in Denmark. In 2001, Johansen et al. reported no association between mobile phone use and increased risk of any types of cancer. In an extended follow up of the same cohort, Schuz et al. (2006a) also found no evidence for an association between cancer risk and mobile phone use among either short-term or long-term users. Using and extending the same cohort Frei et al. (2011) and Schuz et al. (2011) more recently reported that they found no evidence that mobile phone use was related to malignant and benign brain tumours, respectively. In the Danish cohort study, mobile phone subscription records were used as a surrogate for mobile phone use and this could have resulted in considerable misclassification of exposure (Baan et al., 2011).

9.4.1.2 Case-control studies investigating brain tumour

There have been several case-control studies specifically looking at the association between mobile phone use and brain tumours due to the relative rarity of the disease. These studies experience severe limitations with exposure assessment because of their reliance on personal recall of cases and controls of their mobile phone use (Bondy et al., 2008). Four hospital-based case-control studies failed to find any associations between mobile phone use and acoustic neuroma, meningioma, glioma or combined tumours (Muscat et al., 2000; Inskip et al., 2001; Muscat et al., 2002; Warren et al., 2003). However, as noted in a review by Croft et al. (2009), the use of hospital controls may overmatch for exposure, and may be unrepresentative of the general population in other ways that makes it difficult to identify a relationship.

The majority of case-control studies on mobile phone use and brain tumours have been population-based and can be divided into 2 main groups: (a) the INTERPHONE studies and (b) the studies by Hardell and co-workers (some of which have also included use of cordless phones).

9.4.1.3 The INTERPHONE studies

The INTERPHONE project which was coordinated by the International Agency for Research on Cancer was a multi-national series of population based case-control studies (from 13 different countries including Australia) investigating mobile phone use and the associated risk of various cancers in the head and neck. The INTERPHONE studies were based on a common core protocol to enable valid data pooling. The study included approximately 2765 gliomas, 2425 meningiomas, 1121 acoustic neuromas, 109 malignant parotid gland tumours and 7658 controls making it the largest epidemiological study of these tumours to date (Cardis et al., 2007).

Many of the INTERPHONE country centres published their own results, showing no overall association between mobile phone use and head and neck cancer (Christensen et al. 2004, 2005; Hepworth et al., 2006; Hours et al., 2007; Klaeboe et al., 2007; Lahkola et al., 2007, 2008; Lonn et al., 2004a, 2005, 2006; Sadetzki et al., 2007; Schlehofer et al., 2007; Schoemaker et al., 2005; Schuz et al., 2006b; Takebayashi et al., 2006, 2008). However some of the studies reported a small association with acoustic neuroma and glioma for prolonged (more than ten years) ipsilateral mobile phone use. Although these findings may be causal, it is also possible that they are artifactual due to recall bias of phone use and other methodological limitations; these are described in detail by several authors (e.g Ahlbom et al., 2009; Kundi, 2009; Croft et al., 2009; Olsen, 2009).

Pooled analyses of the INTERPHONE studies for malignant brain tumours (glioma and meningioma) and acoustic neuroma showed no overall associations (INTERPHONE Study Group, 2010; 2011). There were suggestions of associations (most pronounced for glioma and acoustic neuroma) in the group representing individuals with the highest cumulative call time. Limitations of the methodology, included selection bias and recall bias preventing firm conclusions of causality being drawn from these observations, as mentioned above. A recent case-case study[9] used INTERPHONE data from 7 participating (European) countries to investigate the location of gliomas in relation to mobile phone use (Larjavaara et al., 2011). The study did not find that gliomas in mobile phone users are preferentially located in the parts of the brain with the highest radio-frequency fields from mobile phones. Contrary to these results another study which used INTERPHONE data from 5 participating countries (mainly non-European) showed increased risks for tumours in the most exposed part of the brain in those with prolonged mobile phone use (Cardis et al., 2011).

9.4.1.4 The Hardell studies

Hardell and colleagues have published a number of papers on wireless phone use and brain tumours since 2000 based on 3 original case-control studies performed in Sweden, some of which have been pooled analyses of the results (all relevant Hardell studies are listed in the Bibliography). Khurana et al. (2009) summarised the Hardell results as statistically significant positive associations between glioma/acoustic neuroma and analogue, digital and cordless phone use. The risks increased with latency period, particularly more than 10 years, and with cumulative mobile phone use more than 2000 hours. Although the Hardell studies are similar to the INTERPHONE studies there are subtle methodological differences which could account for the deviating results. Furthermore the Hardell group shows methodological variation within their own studies. In contrast, the INTERPHONE results originated from 8 independent research groups which followed a common protocol. The Hardell group has also been criticised for the many re-analyses of the same dataset which may give rise to apparent raised risk estimates as a consequence of multiple testing (Health Protection Agency, 2012).

9.4.1.5 Other case-control studies on brain tumour

There have been recent case-control and case-case studies on mobile phones and brain tumours which are not part of INTERPHONE or the Hardell group. Gousias et al. (2009) investigated the use of mobile phones and other potential risk factors with mainly negative results; a positive association of severe cranial trauma was observed, but this association was not statistically significant. In a case-case study, Hartikka et al. (2009) reported increased glioma risk in the part of the brain most heavily exposed from mobile phones; although this result was limited by the small sample size. Two recent French studies by Spinelli et al. (2010) and Baldi et al. (2011) investigated various occupational and environmental risk factors for brain tumour and found no association with mobile phone use. Finally, in another case-case study, Sato et al. (2010) reported an increased risk of acoustic neuroma for mobile phone users with average call duration of more than 20 min/day.

[9] Tumour locations are compared.

9.4.1.6 Meta-analyses of brain tumour studies

There have been five major meta-analyses of brain tumour studies. The first by Lahkola et al. (2006) which combined results from 11 case-control and 1 cohort study found no overall association; although there was no latency analysis. Hardell et al. (2007, 2008) in a meta-analysis of 2 cohort and 16 case-control studies reported no overall association however there was a twofold increased risk of acoustic neuroma and glioma for more than 10 year ipsilateral phone use. Kan et al. (2008) combined 9 case-control studies to show only a marginal increased risk for greater than 10 year use. In a more recent meta-analysis, Hardell et al. (2009) included 11 case-control studies to again show increased risks of glioma and acoustic neuroma and ipsilateral phone use of more than 10 years. Finally Myung et al. (2009) in a meta-analysis of 23 studies also showed no overall association but reported a small increased risk for mobile phone use of 10 years or longer. It must be noted that the issue of heterogeneity and varying methodologies between different studies makes results from meta-analyses difficult to interpret (Croft et al., 2009). Much of this is addressed by the INTERPHONE pooled-analysis since all the studies used a similar methodology.

9.4.1.7 Ecological studies investigating brain tumour

Other research on mobile phones and brain tumours since 2000 includes several ecological studies that have compared temporal trends in brain tumour rates with the prevalence of mobile phone use. Cook et al. (2003) reported that incidence rates for malignancies arising in the head and neck have not changed since the introduction of mobile phones in New Zealand. Contrary to Cook's findings, Johannesen et al. (2004) reported that incidence rates of brain and central nervous system (CNS) tumours increased in Norway during the period 1970-1999; however the authors noted that this increase may be closely related to gender and age. Similarly Baldi et al. (2011) reported an overall increase in CNS tumour incidence in France from 2000 to 2007 although Kohler et al. (2011) did not find an increase in CNS tumours in the US from 1975 to 2007.

Looking at ecological studies specifically on malignant brain tumours, Lonn et al. (2004b) reported increases in the incidence in Nordic countries during the late 1970s and early 1980s, which coincided with the introduction of improved diagnostic methods. After 1983 and during the period with increasing prevalence of mobile phone users, Lonn et al. reported that the incidence remained relatively stable. Deltour et al. (2010) in a follow up study to Lonn et al. (2004b) showed no change in incidence rates in Nordic countries from 1998 to 2003; the authors mentioned that this would be the time when possible associations between mobile phone use and cancer risk would be informative with an induction period of 5 – 10 years. Several other studies have looked at the time trends of brain tumour with two finding an increase in the cancer incidence (Klaeboe et al., 2005; Lehrer et al., 2011) whereas other studies did not show an increase in incidence (Muscat et al., 2006; Roosli et al., 2007; de Vocht, 2011). In Australia, Dobes et al. (2011a,b) reported no overall increase in the incidence of primary brain tumours between 2000-2008 in New South Wales and the Australian Capital Territory; there was a significant increase in malignant brain tumours however this was largely due to an increase in the ≥65-year age group. Finally, a second follow up by Deltour et al. (2012) again showed no change in glioma incidence rates in Nordic countries from 2004 to 2008; in addition the authors performed simulations to show the risk increases seen in some case-control studies appear to be incompatible with the observed lack of incidence rate increase. Similarly, Little et al. (2012) reported stable incidence rates for glioma, between 1992-2008 in the US, which are not

consistent with the raised risks reported by Hardell for mobile phone use; although the authors noted that the incidence rates could be consistent with the modest excess risks in the Interphone study.

Looking at ecological studies specifically on acoustic neuroma, Nelson et al. (2006) found that trends in acoustic neuroma incidence in England and Wales did not lag behind trends in cell phone use in a correlated fashion. More recently Larjavaara et al. (2011) reported that the overall incidence of acoustic neuroma increased in all the four Nordic countries combined between 1987 and 2007, with marked differences between countries. However, the incidence rates more or less stabilised in the late 1990s, showing relatively stable incidence rates and even some decline after 2000. It must be noted that overall these ecological studies are limited in many ways and provide the least evidence for a causal association.

9.4.1.8 Studies on children

An important issue about mobile phone use and risk of brain cancer is the possible hazard to children. Only one study to date has included children, who are considered heavy users of mobile phones and may potentially be more susceptible to harmful effects. In a multicentre case-control study conducted in Nordic countries, Aydin et al. (2011) reported no association between mobile phone use and brain tumour in children aged 7-19 years; there was also no increased risk observed for brain areas receiving the highest amount of exposure. Another international multicentre study (called MOBI-KIDS) involving 13 countries, including Australia, is currently investigating mobile phone use during childhood and adolescence and later onset of brain tumours in people between the ages of 10 and 24 years (http://www.mbkds.net/news/press-release-11052009). Given the current lack of published literature, conclusions cannot be made on whether children are more susceptible than adults when using mobile phones.

Conclusion from studies investigating wireless phones and brain tumour

It is clear from the published literature that no overall increase in the risk of brain tumour or acoustic neuroma due to the use of wireless phones has been observed. There are some indications of an increased risk of glioma and acoustic neuroma in the sub-group with the heaviest use however methodological shortcomings prevent a causal connection. The long-term risk affecting individuals who report heavy use will require further research.

9.4.1.9 Salivary gland tumours

Several studies have investigated mobile phones and salivary gland tumours. Six case-control studies have not found an increased risk including studies by Auvinen et al. (2002), Hardell et al. (2004), Duan et al. (2011) and Soderqvist (2012) and the INTERPHONE studies by Lonn et al. (2006) and Sadetzki et al. (2008). However in an ecological study, Czerniski et al. (2011) reported that the total number of parotid gland cancers in Israel increased 4-fold from 1970 to 2006 (from 16 to 64 cases per year) whereas other major salivary gland cancers remained stable; the authors noted that

increased mobile phone use could be a factor (although mobile phone use prevalence was not reported). Similarly, in another ecological study de Vocht (2011) reported a 2-fold increase in parotid gland tumour incidence together with a dramatic increase in mobile phone subscriptions in England from 1986 to 2008.

9.4.1.10 Other head and neck cancers

Some studies have investigated mobile phones and other head and neck cancers, especially ocular melanoma. Johansen et al. (2002) in an ecological study reported no increasing trend in the incidence rate of ocular melanoma in Denmark, in contrast to the exponentially increasing number of mobile phone subscribers starting in the early 1980s; a similar result was reported by Inskip et al. (2003) in the US. A recent case-control study also found no association between mobile phone use and ocular melanoma (Stang et al., 2009).

For other head and neck cancer sites the case control study by Warren et al. (2009) showed no association with facial nerve tumours. Finally, the INTERPHONE case control study by Takebayashi et al. (2008) and the case control study by Schoemaker and Swerdlow (2009) showed no association with pituitary gland tumours.

9.4.1.11 Haematological cancers

Some case-control studies have specifically investigated haematological malignancies. Hardell et al. (2005) reported an association between T-cell NHL and the use of cellular and cordless telephones, however the result was based on small numbers; there was no association with B-cell NHL. Linnet et al. (2006) found no association between mobile phones and any type of NHL. Kaufman et al. (2009) in a study looking at various risk factors and leukaemia found no clear association with mobile phone use, but durations of use were relatively short. A more recent study found no increased risk for leukaemia (Cooke et al., 2010); there was an increased risk in people who used a phone for more than 15 years but this result was not statistically significant.

9.4.1.12 Other cancers

For any other type of cancer, Hardell et al. (2007) in a case-control study found no association between mobile/cordless phone use and testicular cancer even considering latency; no association was also found with place of keeping the mobile phone during standby, such as trousers pocket. In another case control study the same authors reported no overall association between mobile/cordless phone use and malignant melanoma; however, there was a doubling of the risk for the most exposed area (temporal, cheek and ear) when using phones excessively (cumulative use > 355 hours) (Hardell et al., 2011b).

Conclusion from studies investigating wireless phones and other cancers

Overall, the studies investigating mobile phones and cancers other than brain tumour have generally not shown statistically significant increased risks, although the research for each specific cancer type is limited.

9.4.1.13 Other wireless devices

Since 2000, there has been only one study that has investigated a wireless device other than a mobile or cordless phone and cancer. Schuz et al. (2006c) used subjects from the INTERPHONE project in a case-control study to investigate RF exposure from base stations of DECT cordless phones and the risk of glioma and meningioma. The authors reported no increased risk although the study was limited due to the small number of exposed subjects.

9.4.2 Other (non-cancer) outcomes

9.4.2.1 Subjective symptoms

Numerous cross-sectional studies and surveys since 2000 have investigated the relation between mobile phone use and subjective symptoms such as headaches, tinnitus, dizziness, fatigue, sensations of warmth, sleep disturbance etc:

> (Chia et al., 2000, headache; Oftedal et al., 2000, various symptoms; Sandstrom, 2001, various symptoms; Santini et al., 2002b, various symptoms; Wilen et al., 2003, various symptoms; Al-Khlaiwi and Meo, 2004, various symptoms; Roosli et al., 2004, various symptoms; Balik et al., 2005, ocular symptoms; Balikci et al., 2005, various symptoms; Herr et al., 2005, sleep quality; Szyjkowska et al., 2005, various symptoms; Meo and Al-Drees, 2005a, 2005b, hearing and vision symptoms; Schreier et al., 2006, various symptoms; Al-Khamees, 2007, various symptoms; Davidson and Lutman, 2007, hearing and vestibular symptoms; Mortazavi et al., 2007, various symptoms; Khan, 2008, various symptoms; Kucer, 2008, ocular symptoms; Soderqvist et al., 2008, various symptoms; Thomas et al. 2008a, 2008b, various symptoms; Korpinen and Paakkonen, 2009, various symptoms; Kumar, 2009, headache; Milde-Busche et al., 2010, headache; Mohler et al., 2010, sleep quality; Heinrich et al., 2010, various symptoms; Heinrich et al., 2011, various symptoms; Thomee et al., 2011, various symptoms; Suresh et al., 2011, hypertension; Munezawa et al., 2011, sleep disturbances; Frei et al., 2011, various symptoms; Chu et al., 2011, headache; Mortazavi et al., 2011, various symptoms; Kato and Johasson, 2012, various symptoms; Mohler et al., 2012, sleep quality; Bhargava et al., 2012, various symptoms).

The majority of these studies reported an association between subjective symptoms and mobile phone use. However such studies are highly susceptible to recall bias as outlined in the review by Ahlbom et al. (2004). A more recent review specific to subjective symptoms and exposure to RF by Roosli (2008) also asserts that the large majority of individuals who claim to be able to detect low level RF (electromagnetic hypersensitive, EHS) cannot do so under the double blind conditions of provocation studies. Four separate cross-sectional studies have shown that people that identify themselves as EHS report more symptoms compared to healthy individuals (Schuz et al., 2006d; Rubin et al., 2008; Landgrebe et al., 2009; Roosli et al., 2010). In another cross-sectional study Meg Seng (2011) reported that people with psychiatric morbidity are more likely to report sensitivity to electromagnetic fields including mobile phone use. Furthermore a cross-sectional study by Johansson et al. (2010) reported a difference between people with symptoms related specifically to mobile phones and people with general EHS. Overall the cross-sectional studies on mobile phones and subjective symptoms are un-informative due to their numerous methodological shortcomings which are described in detail elsewhere (Health Protection Agency, 2012).

9.4.2.2 Cognitive effects

There have been a limited number of studies investigating cognitive outcomes since 2000. Three cross-sectional studies have assessed cognitive function in mobile phone users compared to non-users. Cao et al. (2000) reported that mobile phone use could affect reaction time. Lee et al. (2001) reported that mobile phones may have a mild facilitating effect on attention although the authors raised the possibility that mobile phone users may be naturally better at multiple tasking. Finally, Arns et al. (2007) also reported better executive function in mobile phone users which the authors stated may reflect more focused attention possibly associated with a cognitive training effect of mobile phone use. In a cohort study Ng et al. (2011) reported no effect of digital mobile phones on the cognitive function of older people (more than 55 years old).

Some cross-sectional studies have investigated wireless devices and cognitive effects in children. In an Australian study examining cognitive function in secondary school students, Abramson et al. (2009) reported that mobile phone use was associated with faster and less accurate responding to higher level cognitive tasks. However the authors noted that these behaviours may have been learned through the frequent use of a mobile phone. In a follow-up study that examined the same sample of secondary students one year after the original study by Abramson et al. (2009), Thomas et al. (2010a) observed some changes in cognitive function. However the authors advised that this may have been related to the statistical methods used rather than the effects of mobile phone exposure. In a different study Thomas et al. (2010b) using personal dosimetry to assess exposure from mobile phone use (as well as exposure from other RF sources such as cordless phones, mobile phone base stations and wireless internet) reported that exposure to RF fields in the highest quartile was associated to overall behavioural problems for adolescents but not for children. Finally, Khorseva et al. (2011) reported that children that used mobile phones showed a decline in cognitive performance parameters such as increased number of phonemic perception disorders and effects on memory. Overall, there is insufficient evidence to determine whether mobile phone use causes cognitive changes in children (Health Protection Agency, 2012).

9.4.2.3 Developmental effects

Four studies have investigated prenatal mobile phone use and child developmental outcomes. In a cohort study conducted in Spain, Vrijheid et al. (2010) found little evidence for an adverse effect of maternal mobile phone use during pregnancy on the early neurodevelopment of offspring. However Divan and co-workers using the much larger Danish national birth cohort in a series of studies reported associations between prenatal and postnatal mobile phone use and behavioural problems in children (Divan et al., 2008, 2010). A more recent study of the same Danish cohort found no evidence between prenatal mobile phone use and motor or cognitive/language developmental delays among infants (Divan et al., 2011). These findings require further investigation.

9.4.2.4 Male fertility

Since 2000 there have been some cross-sectional studies that have investigated mobile phone use and male fertility. Davoudi et al. (2002), Fejes et al. (2005), Agawarl et al. (2008), Wdowiak et al. (2007) and Gutschi et al. (2011) all reported that mobile phone use can affect male fertility via effects on sperm quality. Also, Kilgallon and Simmons (2005) found that keeping mobile phones close to the

waist decreased sperm concentration compared with men not using mobile phones or storing it elsewhere. In a review of mobile phones and male fertility, Agarwal (2007b) points out that in spite of their consistent results, all these studies had some serious limitations such as the exclusion of other possible risk factors (e.g. life style issues, occupational history, etc).

9.4.2.5 Hearing function

Some, mainly cross-sectional, studies have investigated mobile phone use and hearing. Kerekhanjanarong et al. (2004) observed that people who used a mobile phone more than 60 mins per day showed a decline in hearing threshold however this result was based on a small number of subjects. Similarly Garcia Callejo et al. (2005) and Shayani-Nasab (2006) reported a similar hearing impairment in a larger sample of subjects. Oktay and Dasdag (2006) and Al-Abduljawad (2008) both found that a higher degree of hearing loss is associated with long-term mobile phone use but these results were also based on small numbers. Panda et al. (2010, 2011) also found that long-term and intensive mobile phone use may cause inner ear damage however this result again was based on small numbers. Velayutham et al. (2011) reported that long-term mobile phone use is associated with high frequency hearing loss in the dominant ear (most used to make calls) compared to the non-dominant ear. In general it remains unclear how well these studies controlled for other environmental exposures causing hearing loss.

In a case-control study, Hutter et al. (2010) reported no association between regular mobile phone use and tinnitus however the authors did find a doubling of the risk for prolonged use (≥ 4 years). Tinnitus was also investigated in a cross-sectional study that included EHS individuals and healthy controls; the study found no association between mobile phone use and tinnitus (Landgrebe et al., 2009). The recent review by the Health Protection Agency (2012) has commented that it remains unclear as to how well the epidemiological studies on mobile phones and hearing have controlled for other environmental exposures including direct exposure to sound in the auditory range.

9.4.2.6 Endocrine system effects

There has been a small number of cross-sectional studies that have investigated effects on the endocrine system since 2000. In a study of male electric utility workers Burch et al. (2002) reported that prolonged use of mobile telephones at work may lead to reduced melatonin production, and elevated 60-Hz magnetic field exposures may potentiate the effect. Bergamaschi et al. (2004) reported an association between mobile phone use and thyroid dysfunction however the authors noted that stress could have confounded this result. Similarly, Mortavazi et al. (2009) reported alterations in thyroid stimulating hormone and thyroid hormones following mobile phone use. Finally, Eskander et al. (2012) reported effects on various hormone levels of people who used mobile phones. In general these studies have many methodological limitations including poor study design, lack of exposure assessment and possible errors from confounding and bias.

9.4.2.7 Genetic effects

There have been some cross-sectional studies that have reported genetic effects among mobile phone users (Gadhia et al., 2003, chromosomal damage; Gandhi et al. 2005a, DNA and chromosomal damage; Gandhi et al. 2005b, chromosomal damage and micronuclei in buccal mucosa cells; Yadav et al., 2008, micronuclei in buccal mucosa cells). These studies have been reviewed by Verschaeve

(2009). Two more recent cross-sectional studies by Hintzsche and Stopper (2010) and Ros-Llor et al. (2012) did not find any significant increase in the frequency of micronuclei in buccal and oral mucosa cells (respectively) of mobile phone users. All of these studies suffer from the same methodological limitations as the occupational studies on genetic effects.

9.4.2.8 Other (non-cancer) effects

There have also been several studies that have investigated various other (non-cancer) outcomes. A standout is the Danish retrospective cohort study by Schuz et al. (2009) which generally found no elevated risks for central nervous system diseases among mobile phone subscribers; although there were slightly increased risks for migraine and vertigo. A re-analysis of the same Danish cohort by Harbo Poulsen et al. (2012) found no overall association between mobile phone subscribers and multiple sclerosis; there was a small increased risk among females but this was based on small numbers.

The remaining studies addressing other (non-cancer) effects have mainly been cross-sectional. A study by Zur Nieden et al. (2009) assessed the incidence of various health conditions (cardiovascular, neurodegenerative, hearing function etc) between 1993 and 2005 and found no dramatic increases. Khiat et al. (2006) did not find metabolic changes in the brain amongst mobile phone users. Atay et al. (2009) found no statistically significant difference in iliac bone (which is the most common carriage site for mobile phones) density between subjects with the iliac side exposed to the mobile phone and subjects with the unexposed side. However, Saravi (2011) reported asymmetries in hip mineralization in mobile cellular phone users. Soderqvist et al. (2009a) reported an association between long-term and/or short-term use of mobile and cordless telephones and changes to the blood-cerebrospinal fluid barrier; in a different study on the same subjects Soderqvist et al. (2009b) failed to find any effects on the blood-brain barrier. Parkar et al. (2010) reported no physiological and haematological effects amongst students who used mobile phones although mild alteration of lipid profiles were found. Bhargava et al. (2012) reported that heavy users of mobile phones had an increased salivary flow rate, blood flow rate, and volume of parotid glands. Finally, in a series of ecological studies Hallberg and Johansson have reported a correlation between increased mobile phone use and morbidity (Hallberg and Johhanson, 2004; Hallberg, 2005; Hallberg, 2007; Hallberg and Johhanson, 2009). Overall, the research on all these outcomes is too limited to draw any firm conclusions.

9.5 Conclusion

As mentioned in the epidemiological annex of the RF Standard the epidemiological studies primarily relate to the question of whether there is or is not an increased risk of disease in human populations exposed to RF radiation (ARPANSA, 2002). Epidemiological studies investigating occupational and environmental exposure from RF transmitters since 2000 have not altered the conclusion that no detrimental health effects have been observed consistently in such studies. Research that has progressed quite substantially since the publication of the RF Standard has been on mobile phone use and a possible connection with brain cancer. Although, the studies by the Hardell group and INTERPHONE generally have not shown an overall association, some of the studies have reported an increased risk with acoustic neuroma and glioma for prolonged (more than ten years) or high cumulative mobile phone use. As mentioned earlier these findings could possibly be causal, however

it is also possible that they are artifactual due to recall bias of phone use and other methodological limitations. The gaps in the current epidemiological knowledge may be resolved through well-designed long-term prospective studies such as the Cosmos study in Europe (Schuz et al., 2011).

In May 2011 the International Agency for Research on Cancer (IARC) assessed the carcinogenicity of RF electromagnetic fields and classified them as a possible human carcinogen (Baan et al., 2011). IARC concluded that there is 'limited evidence in humans' for the carcinogenicity of RF fields, based on positive associations between glioma and acoustic neuroma and exposure to RF from wireless phones (mobile phones and cordless phones). IARC also concluded that there is 'limited evidence' in experimental animals for the carcinogenicity of RF fields. Finally IARC concluded that there is only weak mechanistic evidence relevant to RF-induced cancer in humans. It must be noted that the classification by IARC does not provide estimates of what risk of cancer might be posed by any given level of exposure to RF fields.

10. The IARC Monograph and BioInitiative Update

Although the cut-off date for literature that was assessed by the Expert Panel was August 2012 there have been two documents that have been published since then that have created some interest, namely the IARC Monograph on RF fields and an update on the BioInitiative report.

Following the classification of RF electromagnetic fields as a Class 2B or 'possible carcinogen' in May 2011 (Baan et al., 2011), IARC published a monograph in April 2013 which outlined the scientific evidence that was considered by the IARC Working Group in reaching their decision (IARC, 2013). The IARC Monograph does not consider any studies after May 2011 so the research that it covers was included in the literature assessed by the Expert Panel.

The 2012 BioInitiative report updates its original examination of the health risks of RF as well as extremely low frequency fields published in 2007. Similar to the 2007 report, the 2012 update is a collection of separate chapters written by individual authors. The report discusses selected research results indicating the possibility of harmful effects beyond those considered established by the mainstream scientific community. The policy recommendations made by the editors of the report do not necessarily follow from the overall body of scientific evidence on the subject but are available for governments and communities to consider. The BioInitiative 2012 update does not contain any significant research published after the cut-off date for the assessment of literature by the Expert Panel.

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Appendix 1 Major reviews and programs on RF and health since the publication of RPS3

Reviews

Habash RW, Brodsky LM, et al. (2003), *Health risks of electromagnetic fields. Part II: Evaluation and assessment of radio frequency radiation*. Crit Rev Biomed Eng 31(3):197-254.

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Krewski D, Glickman BW, et al. (2007), *Recent advances in research on radiofrequency fields and health: 2001-2003*. J Toxicol Environ Health B Crit Rev 10(4):287-318.

Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) (2007), Possible effects of Electromagnetic Fields (EMF) on Human Health.

SSI's Independent Expert Group on Electromagnetic Fields (2008), Recent Research on EMF and Health Risks.

French Agency for Environmental and Occupational Health Safety (Afsset) (2009). Radiofrequencies

SSM's Independent Expert Group on Electromagnetic Fields (2009), Recent Research on EMF and Health Risks.

Habash RW, Elwood JM, et al. (2009), *Recent advances in research on radiofrequency fields and health: 2004-2007*. J Toxicol Environ Health B Crit Rev 12(4): 250-88.

International Commission on Non-Ionizing Radiation Protection (ICNIRP) (2009), Exposure to high frequency electromagnetic fields, biological effects and health consequences (100 kHz-300 GHz).

Scientific Advisory Committee on Radio Frequencies and Health (CCARS) (2009), Report on radio frequencies and health (2007-2008).

Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) (2009), Health Effects of Exposure to EMF.

Latin American Experts Committee on High Frequency Electromagnetic Fields and Human Health (2010), Non-Ionizing Electromagnetic Radiation in the Radiofrequency Spectrum and its Effects on Human Health.

SSM's Independent Expert Group on Electromagnetic Fields (2010), Recent Research on EMF and Health Risk.

Scientific Advisory Committee on Radio Frequencies and Health (CCARS) (2011), Report on radio frequencies and health (2009-2010).

Advisory Group on Non-Ionising Radiation (2012), Health effects from radiofrequency electromagnetic fields, Documents of the Health protection Agency: Radiation, Chemical and Environmental Hazards Series No. 20.

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Mobile Telecommunications and Health Research Programme, 2001 – Ongoing. http://www.mthr.org.uk/index.htm

Federal Office for Radiation Protection, German Mobile Telecommunication Research Programme, 2002-2008. http://www.bfs.de/en/elektro/forsch_mobil.html

EMF-Net, Research on biological effects of electromagnetic fields, 2004 – 2008. http://ihcp.jrc.ec.europa.eu/our_activities/public-health/exposure_health_impact_met/emf-net

European Health Risk Assessment Network on Electromagnetic Fields Exposure (EFHRAN), 2009-2012. http://efhran.polimi.it/index.html

European Union's 7th Framework Programme for research and technological development, MOBI-KIDS, 2007-2013. http://www.mbkds.net/

Appendix 2 Terms of Reference for the RF Expert Panel

1. Assess whether there are any significant changes to the science underpinning ARPANSA's RF Standard and whether the Standard provides adequate protection by:

   - Examining the reviews prepared by ARPANSA on epidemiological and human experimental research since 2000.
   - Examining major reviews of in vivo and in vitro studies since 2000.
   - Examining any other key individual papers since 2000 that are not included in the above.

2. Assess the research according to whether the findings would have an influence on the guidance provided by the RF Standard.

3. Prepare a final report recommending whether a formal review of the RF Standard be undertaken.

4. Prepare an independent assessment of the RF literature since 2000 which will be published.

Appendix 3 Membership of the RF Expert Panel

Academic experts

Dr Geza Benke (Epidemiology)	Centre for Occupational and Environmental Health Monash University, Vic
Prof. Rodney Croft (Human provocation research)	School of Psychology University of Wollongong, NSW
Prof. Andrew Wood (Biophysics)	Brain and Psychological Sciences Research Centre Swinburne University of Technology, Vic

Appendix 4 Relevant qualifications and credentials of the academic experts

Prof. Andrew Wood

Andrew W Wood, BSc(Hons), MSc, PhD is a Professor in the Brain and Psychological Sciences Research Centre (BPsyC) at Swinburne University of Technology in Melbourne, and was Research Director with the Australian Centre for Radiofrequency Bioeffects Research. After studying physics at Bristol University, UK, he earned a PhD in biophysics from King's College Hospital Medical School, London, UK. At Swinburne, he has taught Medical Biophysics at both undergraduate and postgraduate level for over 30 years. He has supervised twelve successful PhD candidates. He has served on the Radiation Health Committee of the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) for over ten years. He acted as a temporary consultant to the WHO in Malaysia on radiation-related matters. In relation to possible health effects of (non-ionising) electromagnetic fields, Dr Wood conducts laboratory studies both at the cellular level and with human volunteers. He also is involved in theoretical research into mechanisms of action of these fields on biological systems, particularly in relation to dosimetric aspects of standards setting. He has published over 70 articles in peer-reviewed journals. He is an Associate Editor for Bioelectromagnetics.

Prof. Rodney Croft

Rodney Croft obtained a PhD in Psychology, and currently holds the appointment of Professor of Psychology at University of Wollongong. He has been working in the RF Health field for over twelve years, where his expertise has focused on human experimental research, but he has also contributed in the areas of RF in vitro, epidemiology and dosimetry research. Croft was Executive Director of the Australian Centre for Radiofrequency Bioeffects Research from 2004 to 2011, and is currently director of the new NHMRC Centre of Research Excellence, the Australian Centre for Electromagnetic Bioeffects Research. He has worked on a range of RF Health committees in Australia, including the ACIF Code Evaluation Committee and ARPANSA's EME Reference Group, and internationally was an invited contributor to the WHO's 2010 Radiofrequency Research Agenda and the USA National Academy of Science's 2007 Radiofrequency Research Agenda. Croft is actively involved with international EME standards, as a member of the IEEE ICES SC3 and SC4 Standards Committees, the ICNIRP Biology Standing Committee, and as an ICNIRP Main Commission member. He has also been involved in a number of EME consultancies, including for the Australian Defence Force, the Defence Science & Technology Organisation, COMCARE, Shoalhaven City Council and Optus.

Dr Geza Benke

Geza Benke is a Senior Research Fellow in the Centre for Occupational and Environmental Health, Department of Epidemiology and Preventive Medicine, Monash University. He completed his PhD in Epidemiology in 2000 and was awarded an NHMRC Career Development Award in Population Health in 2006. He is currently a chief investigator with the NHMRC funded Project grant 'Do mobile phones affect cognitive development in children'. He has collaborative links with research groups based in Adelaide, Brisbane, Perth and Sydney. Geza has extensive international collaborative links and is the Australian representative on three international exposure assessment committees. Geza is a chief investigator in the Australian center of the the EU-NHMRC funded MobiKids Mobile phone and brain tumor study, co-ordinated by CREAL in Barcelona, Spain. He has presented numerous invited talks regarding RFR exposure and health at conferences and workshops, which include the Plenary session at the Australian Radiation Protection Society conference (Brisbane, 2007), the MTHRM workshop (Royal Society, London, UK, 2007) and the FGF workshop (Stuttgart, Germany, 2006). Geza was President of the AIOH in 2008 and was chairperson of the Institutes Ethics committee for six years. Between 1999 and 2008 he was a member of the Victorian Department of Human Services Radiation Advisory Committee which advises the Minister regarding research involving radiation exposure to humans. Geza has authored over 80 peer reviewed journal papers, book chapters and government reports.

Appendix 5 ARPANSA Literature search

Prior to the formation of the Expert Panel, ARPANSA collected studies on RF and health/biological outcomes that have been published since the year 2000. To find the studies, ARPANSA initially searched the EMF Portal database (http://www.emf-portal.de/) and the IEEE/ICES[10] EMF literature database (http://www.ieee-emf.com/index.cfm) which, are databases dedicated to papers related to electromagnetic fields. In order to find papers that may have been missed by the specialist databases, ARPANSA also searched the PubMed biomedical literature database (http://www.ncbi.nlm.nih.gov/sites/entrez?db=pubmed). Finally, ARPANSA searched the references of all the major reviews on RF and health since 2000 for any papers that were not captured by the previous databases.

The RF literature database assembled by ARPANSA includes all studies with health/biological outcomes from January 2000 till August 2012. The database includes all studies whether they have been peer-reviewed or not as well as all publication types. Non-English-language papers were also included. Papers included, were all types of in vivo, in vitro, human/provocation and epidemiological studies as well as meta- and pooled analyses. The database also includes all the major reviews as well as specialist reviews on in vivo/in vitro research. The RF literature database generally does not contain editorials, methodological papers, case reports, letters or comments[11], although some of these may have been considered in preparing this report. The database generally does not include papers on therapeutic effects. The RF literature assembled in the database between January 2000 and August 2012 includes 298 epidemiological, 238 human/provocation, 453 in vivo and 365 in vitro research papers and 72 general or in vivo/in vitro reviews.

[10] Institute of Electrical and Electronics Engineers/ International Committee on Electromagnetic Safety.
[11] There are some letters and comments included in the RF literature database because they contained results from original research.