WHO RESEARCH AGENDA FOR RADIOFREQUENCY FIELDS

World Health Organization

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LIST OF ABBREVIATIONS

AFSSET	Agence française de sécurité sanitaire de l'environnement et du travail
EEG	Electroencephalography
EMC	Electromagnetic compatibility
EMF	Electromagnetic field
GSM	Global System for Mobile Communications
HSP	Heat shock protein
ICNIRP	International Commission on Non-Ionizing Radiation Protection
JEM	Job exposure matrix
NIEHS	National Institute of Environmental Health Sciences (USA)
NTP	National Toxicology Program (USA)
NRC	National Research Council of the National Academies (USA)
RF	Radiofrequency
SAR	Specific absorption rate
WHO	World Health Organization
WLAN	Wireless local area network

1. INTRODUCTION

Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity (WHO Constitution, 1948)

Telecommunication technologies based on radiofrequency (RF) transmission, such as radio and television, have been in widespread use for many decades. However, there are numerous new applications for the broadcast and reception of RF waves and the use of RF devices such as mobile phones is now ubiquitous. The attendant increased public exposure to RF fields has made its effects on human health a topic of concern for scientists and the general public.

To respond to these concerns, an important research effort has been mounted over the past decade and many specific questions about potential health effects of RF fields have already been investigated by scientists around the world. Nonetheless, several areas still warrant further investigation and the rapid evolution of technology in this field is raising new questions.

Social concern has accrued over the years and is influencing risk management at national and local levels and public acceptance of scientific health risk assessments. Risk management is built on evidence stemming from both scientific knowledge and insights from social studies that investigate this concern. Therefore, this document identifies specific research needs in both basic science relevant to health risk assessment and social science areas pertaining to public concern and risk communication, highlighting their importance in meeting public health needs.

Background

Understanding the health impact of electromagnetic fields (EMFs) falls within the mandate of the World Health Organization (WHO) – in the area of environmental health. WHO aims to help Member States achieve safe, sustainable and health-enhancing human environments and protect populations from biological, chemical and physical hazards. In this context, WHO established the International EMF Project in 1996 in response to general concern over potential health effects of widespread EMF exposure.

One objective of the International EMF Project is to encourage research to study the effects of EMF on humans. This is in line with one of the six core functions of WHO, to: "shape the research agenda, and stimulate the generation, dissemination and application of valuable knowledge". WHO's convening power provides a unique opportunity to bring together experts to identify knowledge gaps and information that are essential for the development of evidence-based public health guidance.

From inception, the International EMF Project has worked to identify knowledge gaps where further research could improve health risk assessments and to present a focused research programme to potential funding agencies. In 1997, it developed a research agenda in order to facilitate and coordinate research worldwide on the possible adverse health effects of EMFs. In subsequent years, the Research Agenda for Radiofrequency Fields has undergone periodic review and refinement. The last major update was undertaken with the input of an ad hoc committee of invited scientific experts and published in 2006 (WHO, 2006).

Impact

Previous Research Agendas for Radiofrequency Fields have been instrumental in assisting countries to develop national funding priorities in this area. This publication aims to be similarly useful for many such programmes currently under review. An update was deemed necessary as a large number of the study topics highlighted in the 2006 edition have been undertaken and new evidence published. To this end, an ad hoc committee of scientific experts met in Geneva in February 2010 to develop this Research Agenda, superseding the 2006 publication.

Guiding principles

WHO encourages the conduct of science that complies with existing standards for best practices in research, including those related to ethics (CIOMS, 2002; WMA, 2008) and to good laboratory practice (OECD, 2010). Such standards are to be applied to govern, manage and improve the quality of research.

Quality of research projects – Research must be of high scientific quality if new studies are to be useful for health risk assessments and standard setting. This requires clearly defined hypotheses; measurable endpoints; sample sizes with sufficient statistical power to answer the relevant questions; and the use of protocols that are consistent with good scientific and ethical practice. Quality assurance procedures should be included in the protocol. Further discussion regarding the quality of

EMF health effect research has been developed over the past several years (ICNIRP, 2002; Monte Verità Workshop, 2005).

Accessibility of data – There is an increasing demand for more accountability and transparency in the reporting of research findings and the sharing of research data through publicly accessible databases (Pisani & AbouZahr, 2010); and for the use of evidence in the development of policy. It is expected that the outcomes of research highlighted in this document will be publicly available and will facilitate the development of consolidated evidence, ultimately providing authoritative health information to support the decisions of policy-makers.

Purpose and audience

The purpose of this Research Agenda is to promote research areas that have relevance to public health, particularly those that can:

- reduce scientific uncertainties through health effects research; and
- respond to public concern through the development of better risk communication.

The document is organized by two main themes: (i) needs for health effects research; and (ii) needs for social science research.

A brief summary of ongoing research is provided for each type of health effect research study, along with overarching issues relevant to the design and analysis of future studies. Research topics relating to social sciences are also of great importance because of the need to better understand the general public's perception of risk and to communicate more effectively on the RF-related health issues. This is seen to be a particularly important area for further research in order to develop better risk communication strategies.

This publication is intended for use by researchers and funding agencies. Researchers are encouraged to use it as a guide to studies that have high value for health risk assessments and risk communication. Research funders and other key partners are encouraged to align global resources to address the Research Agenda in a coordinated fashion in order to minimize any unnecessary duplication of effort and maximize the effectiveness of large research programmes.

Scope

This Research Agenda addresses research priorities of public health relevance within the frequency range of 100 kHz to 300 GHz. By far the majority of topics concern the health effects resulting from exposure to the wireless telecommunications

frequency range. New RF technologies are of particular interest as many employ novel RF modulations such as mobile/cordless phones, wireless data networking, asset tracking and identification, wireless transfer of electrical power and body imaging/scanners.

This document covers exposure of the general public and workers but does not include patients under medical care. Topics relating to measurement methodologies and to electromagnetic compatibility (EMC) issues are also outside the scope of this document.

This Research Agenda is developed ahead of the major hazard/health risk evaluations that the IARC and WHO are due to carry out over the next two years. It focuses on identifying short- and long-term research needs that will enable more complete health risk assessments to be undertaken and communicated more effectively to the public.

2. PROCEDURES

The process that resulted in the publication of this Research Agenda for Radiofrequency Fields is described below.

Initially, background documentation was prepared to assist the WHO Technical Consultation participants – the International Commission on Non-Ionizing Radiation Protection's recent review of RF research (ICNIRP, 2009); a published list of research needs from national agencies (AFSSET, 2009; NRC, 2008) and international organizations (EMF-NET, 2009; SCENHIR, 2009); and a summary of ongoing research were circulated prior to the meeting. The Technical Consultation meeting was held 9-10 February 2010 in Geneva, Switzerland in order to develop a list of research recommendations.

Process for setting research priority

The process for developing the priorities is described below.

1. Create a list of research options, by research domain

A survey was undertaken to compile a list of possible research options to assist the technical group (see below) to formulate the Research Agenda. This aimed to ensure inclusiveness by consulting various stakeholders, including individual researchers, with diverse backgrounds and viewpoints. Members of the International Advisory Committee (IAC) of the International EMF Project helped to compile a list of experts in their respective countries. In November and December 2009, around 400 experts from this list were requested to complete the survey and provide their research recommendations. The 88 replies received contained over 200 research needs that were compiled according to pre-defined areas of research, covering the following research options:

- epidemiology
- human studies
- animal studies
- cell studies
- mechanisms of interaction

- dosimetry and exposure assessment
- social sciences.

A rationale was requested for each research option; many of the topics were either identical or sufficiently similar to allow them to be combined.

2. Gather technical experts and define the context

A technical group comprising nineteen experts (see Annex 1) was assembled in order to identify the future RF research priorities. The context of the document was defined in plenary in terms of the scale (global), target population (general public and workers) and time period (both short- and long-term). Each research activity is classified by:

- high-priority research needs: studies to fill important gaps in knowledge that are needed to reduce significantly uncertainty in the current scientific information and to improve significantly health risk communication
- other research needs: studies to better assist understanding of how RF EMF exposure impacts health and public health concern, which would contribute useful information to health risk assessment and risk communication.

3. Set criteria for priority setting

The criteria for setting priorities were developed in plenary at the beginning of the meeting (see Annex 2):

- relevance to public health (scientific concern, public concern, exposure relevance)
- potential for filling knowledge gap
- scientific suitability (study design and method)
- feasibility (in terms of cost, ethical issues, timescale).

Selection of experts

WHO places great value on the technical quality and independence of the participating experts and on the transparency of the selection process. In addition to scientific and technical excellence, WHO considers the need for experts who possess diverse and complementary scientific backgrounds and provide a balanced representation of gender and geographical regions. Previous experience and participation in national or international scientific bodies is also considered desirable.

Experts were invited to participate solely on the basis of their individual scientific expertise. They do not represent the governments of the countries of which they are citizens, or the institutions with which they are associated. The experts designated to participate in the meeting received no remuneration from WHO but WHO bore exclusive responsibility for travel costs and subsistence allowances.

Before participating in this Technical Consultation, the selected experts were required to declare any potential interests associated with the subject (see Annex 3). Additionally, all participants were asked to disclose any relevant conflicts to other workshop participants.

3. HEALTH EFFECTS RESEARCH NEEDS

This chapter is ordered according to the weight that each research activity carries in human health risk assessment: epidemiology; human studies; animal studies; cellular studies; and mechanisms. Whilst epidemiological and human studies directly address endpoints related to human health, it should be recognized that cellular and animal studies are of value in assessing causality and biological plausibility. Dosimetry is considered separately but is important for all areas of research.

3.1 Epidemiology

Epidemiological studies are of primary importance in health risk assessment as they directly address the exposure and disease occurrence in the population. A number of epidemiological studies of health effects of RF EMF, including some identified in the 2006 Research Agenda, are currently completed or ongoing. The most important studies include those listed below.

- *A large prospective cohort study of mobile telephone users that includes incidence as well as mortality data.*

  The COSMOS cohort study includes five countries (Denmark, Finland, the Netherlands, Sweden, United Kingdom). It will evaluate changes in the frequency of specific symptoms over time (such as headaches and sleep disorders) and also the risks of cancers, benign tumours, neurological and cerebrovascular diseases. This international cohort study intends to follow the health of a target figure of approximately 250 000 European mobile phone users; recruitment is ongoing (February 2010). Almost all case-control studies address brain cancer but the cohort study has the potential to study other brain-related disorders and other diseases. Changes in technology and use of mobile phone practices can be captured in the longitudinal design. This study remains a high priority and should be continued until a reasonable follow-up time (minimally 10-15 years) has been achieved to evaluate potential long-term risks.

- *A large-scale multinational case-control study of brain cancer risk in children in relation to mobile phone use, following a feasibility study.*

  Two different studies have been developed in order to address this topic. First, the CEFALO case-control study was performed in Denmark, Norway, Sweden, Switzerland and the United Kingdom to investigate the risk for brain tumours

in children aged 7 to 19 years in relation to mobile phone use during the study period 2004–2008. The results should be published in 2011.

The second study, MOBI-KIDS, is an international multicentre case-control study on risk factors for brain cancer in young people. Over a study period of 5 years and in 13 countries, nearly 2000 young people between 10 and 24 years with brain tumours and a similar group without a brain tumour will be invited to participate. After a preparatory phase, recruitment is expected to start in the latter half of 2010.

- *INTERPHONE*

  This international case-control study of intracranial tumours and tumours of the parotid gland started in 2001 and has been conducted in 13 countries. Results of some national and international analyses have been published and the full collaborative analysis for gliomas and meningiomas was released recently (INTERPHONE Study Group, 2010). The overall analysis showed no increased risk for glioma or meningioma with mobile phone use over 10 years. There were some indications of increased risk of glioma: (a) in the subgroup with highest cumulative call-time in subjects who reported usual phone use on the same side of the head as their tumour, and (b) for tumours in the temporal lobe. Biases and errors prevent a causal interpretation. Nevertheless, these findings require further elaboration and could be evaluated in the recently launched prospective cohort study. Future analyses of the INTERPHONE data could include evaluation of the tumour risk in relation to estimated field strength from mobile phones in various parts of the brain.

  Validation studies addressing the sources of error in case-control studies – including exposure misclassification, recall bias and selection bias – have been conducted in conjunction with the INTERPHONE study. The results facilitate the interpretation of these data as well as results from similar studies. However, the volume of data obtained from these studies and their inherent sources of error suggest that there is no justification for further case-control studies of brain tumours among adults using self-reported exposure data.

Besides these large-scale studies, smaller case-control studies have been conducted in different countries. Several meta-analyses of brain tumour studies have been published (e.g. Ahlbom et al., 2009; Hardell et al., 2008; Kan et al., 2008; Lahkola, Tokola & Auvinen, 2006; Myung et al., 2009). Their coverage of studies has varied, affecting the overall results, but most have indicated heterogeneity between study results. This may be attributable to differences in methods and procedures and the inconsistency highlights the uncertainties inherent in case-control studies that rely on self-reported mobile phone use.

Epidemiological studies on far field whole-body exposure from mobile phone base stations and other transmitters have been conducted in the German research programme (http://www.emf-forschungsprogramm.de/) and are ongoing in the Swiss research programme (http://www.nfp57.ch/e_index.cfm). These studies focus on well-being and nonspecific symptoms of ill health, using personal exposure meters to obtain more reliable estimations of exposure. The results published so far (BfS, 2008) do not indicate effects from such exposures in the everyday environment, although longitudinal studies are still scarce.

High-priority research needs

- **Prospective cohort studies of children and adolescents with outcomes including behavioural and neurological disorders and cancer**

  Rationale: As yet, little research has been conducted in children and adolescents and it is still an open question whether children are more susceptible to RF EMF since the brain continues to develop during childhood and adolescence. Also, children are starting to use mobile phones at a younger age. Given the existence of large-scale cohort studies of mothers and children with follow-up started during or before pregnancy, an RF sources component could be added at a reasonably low cost. Billing records for mobile phones are not valid for children, therefore the prospective collection of exposure data is needed. For neuropsychological studies, one challenge is to distinguish the "training" of motor and neuropsychological skills caused by the use of a mobile phone from the effects of the RF field. Any future study should try to address this issue. In any case it should be of longitudinal design, thereby allowing the study of several outcomes and changes in technology and the use of mobile phones as well as other sources of RF EMF exposure, such as wireless laptops.

- **Monitoring of brain tumour incidence trends through well-established population-based cancer registries, if possible combined with population exposure data**

  Rationale: If there is a substantial risk associated with mobile phone use, it should be observable in data sources of good quality. Such time trend analyses can be performed quite quickly and inexpensively. By using modern statistical techniques for analysing population data it should be possible to link changes in exposure prevalence in the population to the incidence of brain tumours and, if high-quality surveillance data are available, the incidence of other diseases at the population level. Given the shortcomings in the exposure assessment and participation of previous studies based on individual data, an ecological study would have benefits that may outweigh its limitations.

Other research needs

- **Case-control studies of neurological diseases provided that objective exposure data and confounder data are available and reasonable participation is achieved**

  Rationale: Neurological endpoints, such as Alzheimer disease and Parkinson disease, may be as biologically plausible as brain cancer and an increased risk would have a major public health impact. This study could give an early warning sign that can be elaborated further in the prospective cohort studies. An analysis of time-trends in neurological disease could also serve as an early warning sign. However, a feasibility study would be necessary in order to determine whether a good quality case-control study could be carried out.

3.2 Human studies

A large number of provocation studies have been conducted in adults. In general, earlier provocation studies indicating effects of RF EMF on cognitive performance have not been replicated in more recent and higher-quality provocation studies. Therefore, further research on these endpoints is not a high priority. In contrast, recent provocation studies using Global System for Mobile Communications (GSM) signals have reported effects on brain function, notably on sleep electroencephalography (EEG) and resting EEG (e.g. van Rongen et al., 2009). These studies have shown moderate consistency to date. The significance of such biological effects on health per se is unknown, but so far the changes recorded have not been found to relate to any specific health effects. It is important to clarify the neural processes underlying possible RF field effects on the brain.

Research with children was identified as a priority in the 2006 Research Agenda:

- *If ethical approval can be obtained, acute effects on cognition and EEGs should also be investigated in children exposed to RF fields in the laboratory.*

  There have been only a few such studies to date.

There have been several recent high-quality provocation studies of people reporting health symptoms that they attribute to RF EMF exposure.[1] The results of these studies do not show any relation between the symptoms that these individuals experience and RF EMF exposure. Nevertheless, more research on the causes and treatment of this condition would be valuable in a broader socio-medical context and is recommended in the social sciences section below.

1. Sensitivity to EMF has been generally termed electromagnetic hypersensitivity (EHS). A more general term for sensitivity to environmental factors is idiopathic environmental intolerance (IEI) (WHO, 2005), i.e. environmental intolerance of unknown cause.

High-priority research needs

- **Further RF EMF provocation studies on children of different ages**

  Rationale: Current research has focused primarily on adolescents; very little is known about possible effects in younger children. Longitudinal testing at different ages, for example by studying children already participating in current cohort studies, is recommended. This would allow consideration of the influence of potentially confounding factors such as lifestyle.

- **Provocation studies to identify neurobiological mechanisms underlying possible effects of RF on brain function, including sleep and resting EEG**

  Rationale: These studies should include validation of these effects using a range of brain imaging methods. They should also include studies investigating possible thresholds and dose-response relationships at higher exposure levels such as those encountered during occupational exposure.

Other research needs

No other research needs were identified.

3.3 Animal studies

Animal studies are used when it is unethical or impractical to perform studies on humans. They have the advantage that experimental conditions can be controlled, even for chronic exposures.

The 2006 Research Agenda identified the following as high priority.

- *Studies investigating effects from exposure of immature animals to RF fields on the development and maturation of the CNS, and on the development of the haematopoietic and immune systems using functional, morphological and molecular endpoints. Genotoxic endpoints should also be included. Experimental protocols should include prenatal and/or early postnatal exposure to RF fields.*

  Several studies of acute prenatal exposure and one multigenerational study (e.g. Lee et al., 2009; Ogawa et al., 2009; Sommer et al., 2009) found no harmful effects of exposure on the fertility and development of the animals. However, a study of the effects of exposure of young animals (Kumlin et al., 2007) found a slight improvement in one of several measures of adult behavioural performance. Other studies of the effects of prenatal or early life exposure are being carried out in France, Germany and Italy.

The possible carcinogenicity of RF field exposure has been investigated in a large number of long-term animal studies which included classical rodent bioassays, genetically predisposed animals and studies of co-carcinogenicity. With only a few exceptions, these studies have provided no evidence of carcinogenic effects (Juutilainen et al., 2010). The National Institute of Environmental Health Sciences (NIEHS) and the National Toxicology Program (NTP) are funding a large scale study in the United States that will use mice and rats; include in utero, neonatal, juvenile and adult exposure; and test both cancer-related and non-cancer endpoints. The results of the study are expected to be available in 2014 (NTP, 2009), after which the need for further large, long-term animal cancer studies should be reassessed.

Since the 2006 Research Agenda, major improvements have been achieved in the design and characterization of exposure systems, in particular for free-moving animals. It is of critical importance that future experiments include good dosimetry and statistical analysis, as well as adequate statistical power, a blind design and proper sham exposure.

High-priority research needs

- **Effects of early-life and prenatal RF exposure on development and behaviour**

  Rationale: There is still a paucity of information concerning the effects of prenatal and early life exposure to RF EMF on subsequent development and behaviour. Such studies are regarded as important because of the widespread use of mobile phones by children and the increasing exposure to other RF sources such as wireless local area networks (WLANs) and the reported effects of RF EMF on the adult EEG. Further study is required which should include partial (head only) exposure to mobile phones at relatively high specific absorption rate (SAR) levels.

- **Effects of RF exposure on ageing and neurodegenerative diseases**

  Rationale: Age-related diseases, especially neurodegenerative diseases of the brain such as Alzheimer disease and Parkinson disease, are increasingly prevalent and are therefore an important public health issue. Mobile phone use typically involves repeated RF EMF exposure of the brain; a recent study has suggested that this type of exposure could affect Alzheimer disease in a transgenic mouse model for this condition (Arendash et al., 2010). There are a few ongoing studies of possible RF EMF effects on neurodegenerative diseases but further studies are required to investigate this subject more fully.

Other research needs

- **Effects of RF exposure on reproductive organs**

  Rationale: The available data concerning possible effects of RF EMF from mobile phones on male fertility are inconsistent and their quality and exposure assessments are weak. In vivo studies on fertility should consider effects on both males and females and investigate a range of relevant endpoints including RF EMF effects on the development and function of the endocrine system.

3.4 Cellular studies

Studies in tissues, living cells and cell-free systems play a supporting role in health risk assessments. Cellular model systems are candidates for testing the plausibility of mechanistic hypotheses and investigating the ability of RF EMF exposures to have synergistic effects with agents of known biological activity. Cellular studies have the potential to identify clear responses to RF EMF exposures and therefore can be used as a screen for possible effects of new RF signals.

The following research needs were identified in the 2006 Research Agenda.

- *Independent replication studies of recently reported findings on HSP and DNA damage using low-level (below 2 W/kg) and/or modulation- or intermittency-specific signals. The dependence of the effects on SAR levels and frequency should be included.*

  A number of studies of RF genotoxicity and effects on gene and protein expression have been carried out – including the recommended replication studies on heat shock protein (HSP) expression and phosphorylation (Hirose et al., 2007; Lee et al., 2006; Valbonesi et al., 2008; Vanderwaal et al., 2006) and on DNA damage using the comet assay – with mostly negative results (Sakuma et al., 2006; Sannino et al., 2009; Speit, Schütz & Hoffmann, 2007; Stronati et al., 2006; Valbonesi et al., 2008; Zhijian et al., 2009). Other studies await publication. One group in China is exploring whether the impact of RF EMF on cellular DNA is of cell type dependence by using gamma-H2AX as a more sensitive and earlier DNA damage biomarker (Zhang et al., 2006).

- *Studies of RF effects on cell differentiation, e.g. during haemopoiesis in bone marrow, and on nerve cell growth using brain slices/cultured neurons.*

  Few studies of RF EMF effects on cell differentiation have been completed, in contrast to studies using cultured neurons (Buttiglione et al., 2007; Del Vecchio et al., 2009; Joubert et al., 2007 & 2008). Several studies of neuronal differentiation following RF EMF exposure are ongoing in Italy and Germany.

In principle, the use of high-throughput techniques (-omics) should help identify targets of field exposure when the studies are well-conducted and use rigorous statistical techniques. (e.g. Blankenburg et al., 2009; McNamee & Chauhan, 2009). However, many published studies are technically incomplete as they lack sufficient experimental repetition, replication and confirmation through the use of more precise quantitative measures. In addition, the magnitude of any changes is usually small and difficult to interpret. The use of these high-throughput techniques in exploring possible RF EMF effects may become a priority once these issues have been addressed.

High-priority research needs

None identified.

Other research needs

- **Identify optimal sets of experimental tests to detect cellular response after exposure to RF fields used in new technologies and co-exposures of RF EMF with environmental agents**

  Rationale: A number of in vitro studies investigating the effects of exposure to mobile phone frequencies/signals, or co-exposures of RF EMF with chemical or physical agents, have been published in the last fifteen years. Results obtained have been inconsistent and contradictory, not least because of the use of a large variety of cell types and study approaches. A set of highly sensitive, well-harmonized cellular and molecular methods should be developed in order to screen the toxic potential of new types of RF signals used in new technologies and of co-exposures of RF EMF and environmental agents – especially those suspected to have toxic effects. This research must be multicentred in order to allow the widest possible acceptance and application of this screening tool.

- **Further studies on the influence of genetic background and cell type: possible effects of mobile phone type RF exposure on a variety of cell types using newer, more sensitive methods less susceptible to artefact and/or bias**

  Rationale: More rigorous quantitative methods should be employed in the evaluation of positive results that suggest a specific cell type response, e.g. of embryonic cells (Czyz et al., 2004; Franzellitti et al., 2010), raising the possibility that RF impacts specific cell subpopulations or cell types. These studies should include a variety of cell types such as stem cells and cells with altered genetic backgrounds.

3.5 Mechanisms

The accepted health effects of RF field exposure are caused by temperature elevation; non-thermal effects are defined as bioeffects that are not caused by temperature elevation. However, in practice it is often difficult to assess whether temperature elevation has taken place. No alternative mechanism of interaction has been identified to date (Sheppard, Swicord & Balzano, 2008; Valberg, van Deventer & Repacholi, 2007).

No high-priority or other research needs were identified in the 2006 Research Agenda.

A recent communication of research findings has reported that non-linear responses indicative of the possible demodulation of a modulated RF signal did not occur at around 1 GHz carrier frequencies in cells in vitro (Kowalczuk et al., 2009).

High-priority research needs
None identified.

Other research needs
None identified.

3.6 Dosimetry

Dosimetric evaluations are of critical importance in the design and interpretation of experimental studies involving humans, cells and animals. They are also indispensable for developing and validating exposure assessment methods in epidemiological studies. They provide methods for assessing product safety and compliance with exposure guidelines and produce comparative exposure data for risk communication.

Exposure should be assessed using harmonized methodologies. It is necessary to consider multisource exposure rather than focus solely on exposure arising from single sources. Specific exposure information on different types of RF sources should be disseminated adequately (e.g. print, web) in order to permit future multisource exposure assessment.

The 2006 Research Agenda identified the following high-priority need:

- *Research is needed to document rapidly changing patterns of wireless communication usage and exposure of different parts of the body (especially for children and foetuses), including multiple exposure from several sources.*

Several studies have been published regarding exposures from novel sources and exposure scenarios (Foster, 2007; Martinez-Búrdalo et al., 2009) and others are ongoing. With multiple sources, a great number of scenarios could potentially be considered. Published studies have defined and evaluated certain representative scenarios and generally these have found combined exposures that are small in relation to exposure guidelines (Schmid et al., 2007a & 2007b). The situation of a mobile phone (or another device of similar power) held very close to the body/head is a uniquely high exposure condition and the presence of other sources near the body does not seem to modify appreciably the localized SAR in the vicinity of such a device. Dosimetric research is also active in designing human, animal and in vitro exposure systems, including live cell imaging, which can be applied in the context of emerging technologies.

- *Further work on dosimetric models of children of different ages and of pregnant women. Improvement in dosimetric models of RF energy absorption in animals and humans combined with appropriate models of human thermoregulatory responses (e.g. inner ear, head, eye, trunk, embryo and foetus).*

  Model families of phantoms of various ages and both sexes are now available (Christ et al., 2010a; Lee et al., 2010) and various studies of the SAR distribution in children of different ages, pregnant women and foetuses have been published (Christ et al., 2010b; Dimbylow & Bolch, 2007; Dimbylow, Nagaoka & Xu, 2009; Uusitupa et al., 2010). Further work, including modelling the SAR distribution at different gestational stages, is being pursued in several countries.

  Macro- and micro-thermal studies, including perfusion models, are ongoing in several countries. Small anatomical structures in the body have been considered, including temperature rises at sub-millimetric distance scales (Schmid, Überbacher & Samaras, 2007; Schmid et al., 2007c). No significant temperature variations have been found at small distance scales with current telecommunications waveforms and the appropriateness of the 10 g mass presently used in averaging SAR has been shown (Hirata & Fujiwara, 2009). Further work in this area would have greater priority if temperature rise was to be considered for inclusion as a restricted quantity in future exposure guidelines.

- *Microdosimetry research (i.e. at the cellular levels) that may yield new insights concerning biologically relevant targets of exposure as an "other" research need.*

  Little work appears to have been stimulated, possibly because of the continuing lack of a reproducible biological effect at non-thermal levels. If such an effect were found then microdosimetry research would likely play an important part in understanding the effect.

Research and development is also active in the development of instrumentation and methods for demonstration of compliance for specific products and exposures

in the workplace. Both these areas of work are being stimulated by regulatory requirements in various parts of the world.

High-priority research needs

- **Assess characteristic RF EMF emissions, exposure scenarios and corresponding exposure levels for new and emerging RF technologies; also for changes in the use of established technologies**

  Rationale: The work should address the latest developments in areas such as mobile/cordless phones, wireless data networking, asset tracking and identification, wireless transfer of electrical power and body imaging/scanners. It should also consider the possible combined effect of exposure to multiple sources. This will allow exposures from new devices/scenarios to be compared with those that are more familiar and with exposure guidelines for risk communication purposes. This information will also be of value for exposure assessment in epidemiological studies and in the design of biological exposure systems.

- **Quantify personal exposures from a range of RF sources and identify the determinants of exposure in the general population**

  Rationale: The quantification of personal exposure from a range of RF sources will provide valuable information for risk assessment and communication, and for the development of future epidemiological research. It is particularly useful for global exposure assessment in view of the upcoming WHO health risk assessment. The study will also provide baseline data for identification of any changes in the level of exposure and the dominant contributing factors over time. Subgroup analyses should be carried out to identify any influence from demographic aspects of the user as well as the microenvironment in which the exposure occurs. Exposure metrics should also be considered, especially in combining localized exposures from body-worn devices and whole-body exposures.

Other research needs

- **Monitoring of personal exposure of RF workers**

  Rationale: The exposure patterns of both workers and the general public change continuously, mainly due to the development of new RF technologies. However, workers encounter industrial sources and exposure situations that lead to much higher energy deposition in the body. When epidemiological studies on RF workers are performed, it is imperative to monitor adequately their RF exposure. New instruments are needed to address the lack of adequate measurement tools for evaluating this type of exposure e.g. portable devices suitable for measuring different frequencies and waveforms. In addition, a study of the feasibility of monitoring the personal exposure of RF workers is required for future epidemiological studies. Such studies would be facilitated by the production of a job exposure matrix (JEM) for RF workers – in which job designations can be characterized by their exposure.

4. SOCIAL SCIENCE RESEARCH NEEDS

Public concerns about possible adverse health effects of RF fields from wireless communication technologies continue unabated in media and policy forums. These concerns influence risk management and public acceptance of scientific health risk assessments. Risk management should build on evidence from both scientific risk assessments and insights from social studies that investigate these concerns through well-formulated research. Risk communication is central to this process. However, by their very nature, the results of scientific research are typically provisional rather than definitive. The results of any single study will typically provide a limited contribution to definitive determinations of health impacts or effects that the public and policy-makers often seek. These general issues in the biomedical science-to-policy continuum complicate RF risk communication and highlight the need for complementary forms of social science research.

A number of social issues were highlighted in the 2006 Research Agenda. Some of the topics identified have since been addressed and are summarized below.

- *Assess impacts of precautionary measures on public concern and the adoption of voluntary or policies.*

  The research has mostly explored the question of whether or not awareness of a precautionary approach has the effect of attenuating or intensifying public concern. Several research groups have addressed this question, suggesting that precautionary approaches tend to intensify rather than attenuate perceptions of risk (Barnett et al., 2007 & 2008; Schütz, Wiedemann & Clauberg, 2007; Timotijevic & Barnett, 2006; Wiedemann & Schütz, 2005; Wiedemann et al., 2006). Conceptual scientific considerations of precaution from a social perspective can be found in the work of Hom et al. (2009) and Stilgoe (2007).

- *Evaluate the success of programmes for public and stakeholder participation in various countries.*

  No such rigorous evaluations of programmes for public and stakeholder participation were identified but some published case studies analyse the results of public participation (or lack thereof) in decision-making processes around base station siting issues (Drake, 2006; Law & McNeish, 2007). These studies, and a more theoretical paper (Hom, Moles Plaza & Palmén, 2009), have the core theme that it is unhelpful to characterize public responses as irrational – more refined analysis of public responses is required. However, an experimental study

by Wiedemann & Schütz (2008) suggested that increased information provision and participation does not necessarily translate into greater acceptance of the siting process.

- *Investigate risk perception of individuals, including studies on the formation of beliefs and perceptions about the relationship between RF exposure and health.*

  The studies published in this area since 2006 can best be characterized as exploring the psychological processes that underline responses to risk, using EMF as an exemplar hazard. Siegrist, Keller & Cousin (2006) demonstrate the importance of emotion in responses to EMF. Siegrist, Cousin & Frei (2008) identify biases that help explain why lay assessments of risk differ from professional risk assessments. For example, confidence was greater in studies that showed a risk, compared to those showing no risk. Confidence was also greater when risk estimates were in line with prior attitudes, compared to those at variance with prior attitudes. Finally, White et al. (2007) explored the variability of risk estimates depending on who is identified as the target of the risk (e.g. self, others or children). Most notably they demonstrated that preferences for handset regulation were predicted by perceptions of risk to others, along with perceived benefits to self.

In view of the developments in science and society, the following social science research topics are currently considered important. All the studies described below are needed and there is no specific priority.

- **Investigate the determinants and dynamics of RF EMF-related health concerns and perceived health risks**

  Rationale: While there is knowledge about several general factors associated with perceived risk, much less is known about the specific determinants of EMF risk perception – how people think about EMF technology and select, process and respond to new information. Knowledge on these issues would enable policy-makers to take measures to better address people's perception of RF EMF health risks. In particular, more study is needed to determine how individual levels of concern may develop and vary over time. Available research suggests that the proportion of people concerned about health risk from RF EMF technologies has been stable over recent years but there is little knowledge whether this holds true at the individual level. This makes it difficult to take adequate measures to address concerns overall. Hence, longitudinal studies monitoring the factors affecting changing patterns of risk perception over time in the context of risk communication and management strategies would be valuable.

- **Investigate the effectiveness of different formats for communicating scientific evidence regarding health effects of RF EMF exposure and risk information to the public**

  Rationale: The public often appears to demonstrate considerable misunderstanding of scientific evidence, especially when there is a lack of conclusive evidence about potential health hazards, as is the case with RF EMF exposure. It is therefore important to improve the provision of information in order to enable people to make properly informed and balanced judgments and decisions about their health and safety. In the process of informing, the public's perspective should explicitly be taken into account. Novel tools for characterizing and summarizing evidence of the health effects of RF EMF exposure should be developed explicitly from a communication perspective. Different communication formats should be evaluated empirically by considering people's concerns and perceived risk; their ability to manage health threats; and their trust in scientists, risk communicators and authorities.

- **Investigate whether and how people's perception of RF EMF health risks can affect their well-being**

  Rationale: A number of well-conducted laboratory studies show no relation between the health symptoms experienced by some individuals and RF EMF exposure. Yet, perceived hypersensitivity to RF EMF remains an issue of concern for those affected and for the societies in which they live. Further studies should be carried out in order to elucidate the psychological and psychosocial processes that may influence perceived RF EMF hypersensitivity. Interventions which may alleviate the symptoms should also be explored further. WHO considers this perceived hypersensitivity to be a form of idiopathic environmental intolerance (WHO, 2005) as it resembles other disorders associated with exposure to low-level environmental factors, therefore research may be broadened to comparative hypersensitive reactions to other environmental factors.

- **Investigate how RF EMF technologies have been handled in a larger social context**

  Rationale: Several recent studies have described the multidimensional and interrelated character of public concerns as well as the interdependence of the science and the social aspects of mobile communications technology (e.g. Bickerstaff, Simmons & Pidgeon 2007; Law & McNeish, 2007; Moore & Stilgoe 2009; Wiedemann & Schütz, 2008). This interdependence can be explored by looking at how different stakeholders have addressed RF technologies. Such studies could include the history and context of specific RF technologies, regulations, safety measures and media reports or country comparisons of how science and policy relations in this field have developed.

5. SUMMARY

RF Research Agenda recommendations	
Health effects research	
Priority	**Epidemiology**
High	Prospective cohort studies of children and adolescents with outcomes including behavioural and neurological disorders and cancer
High	Monitoring of brain tumour incidence trends through well-established population-based cancer registries, if possible combined with population exposure data
Other	Case-control studies of neurological diseases provided that objective exposure data and confounder data are available and reasonable participation is achieved
	Human studies
High	Further RF EMF provocation studies on children of different ages
High	Provocation studies to identify neurobiological mechanisms underlying possible effects of RF on brain function, including sleep and resting EEG
	Animal studies
High	Effects of early-life and prenatal RF exposure on development and behaviour
High	Effects of RF exposure on ageing and neurodegenerative diseases
Other	Effects of RF exposure on reproductive organs
	Cellular studies
Other	Identify optimal sets of experimental tests to detect cellular response after exposure to new RF technologies and co-exposures of RF EMF with environmental agents
Other	Further studies on the influence of genetic background and cell type: possible effects of mobile phone type RF exposure on a variety of cell types using newer, more sensitive methods less susceptible to artefact and/or bias
	Mechanisms
	None
	Dosimetry
High	Assess characteristic RF EMF emissions, exposure scenarios and corresponding exposure levels for new and emerging RF technologies; also for changes in the use of established technologies
High	Quantify personal exposures from a range of RF sources and identify the determinants of exposure in the general population
Other	Monitoring of personal exposure of RF workers

RF Research Agenda recommendations	
Social science research	
NA	Investigate the determinants and dynamics of RF EMF-related health concern and perceived health risks
NA	Investigate the effectiveness of different formats for communicating scientific evidence regarding health effects of RF EMF exposure and risk information to the public
NA	Investigate whether and how people's perception of RF EMF health risks can affect their well-being
NA	Investigate how RF EMF technologies have been handled in a larger social context

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ANNEX 2. AGENDA OF THE TECHNICAL CONSULTATION

WHO Headquarters - Geneva, Switzerland - Room M 505 9-10 February 2010
WHO Research Agenda for Radiofrequency Fields (2010) AGENDA

Tuesday 9 February		**Chair: E. van Deventer**
9:30	**Welcome and introductions**	M. Neira, Director PHE
9:45	**Purpose of the meeting and expected outcome**	E. van Deventer
10:00	**Checklist for health research priority setting**	R. Terry
10:30	**Coffee break**	
11:00	**Discussion** Criteria for selecting research priorities Review of draft document	
12:30	**Lunch**	
13:30	**Breakout groups** Review of draft text regarding ongoing research Ranking research priorities	
15:30	**Coffee break**	
16:00	**Breakout groups (cont'd)**	
17:30	**Adjourn**	

Wednesday 10 February		**Chair: R. Saunders**
9:00	**Plenary discussion** Reporting from breakout groups	
10:30	**Coffee break**	
11:00	**Plenary discussion (cont'd)**	
12:30	**Lunch**	
13:30	**Plenary discussion (cont'd)** Steps forward Conclusions, next steps	
16:00	**Close of meeting**	

ANNEX 3.
DECLARATIONS OF INTERESTS

The Technical Consultation participants completed a WHO form for declaration of interests prior to the meeting. At the start of the meeting, all participants were asked to confirm their interests and to provide any additional information relevant to the subject matter of the meeting.

The following participant declared current or recent (<3 year) financial interests related to commercial organizations as listed below:

Kuster: Near-Field Technology AG, SPEAG AG, ZMT AG, Imricor Inc. USA, MaxWave AG, Apple

Several participants declared academic interest in the subject matter of the meeting. These were not regarded as conflicts of interest since they formed the basis of the expertise of the panel.

The following participants declared no conflict of interests in the subject matter of the meeting:

Haggard, Marino, Olsen, Röösli, Soneryd, Timmermans

Given their roles as experts or advisers to professional or government bodies, several participants noted that they had made public statements regarding the subject matter of the meeting. These were not considered to be conflicts for the purposes of the meeting.

On the basis of their declared interests in the subject of the meeting, and with regard to the nature and extent of financial and/or academic interests, the following panel participant(s) took no part in the final session of the meeting, during which the research priorities were confirmed, or in the finalization of the recommendations subsequent to the panel meeting:

Kuster

No experts were asked not to participate in the meeting on the basis of declared personal and commercial interests.

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