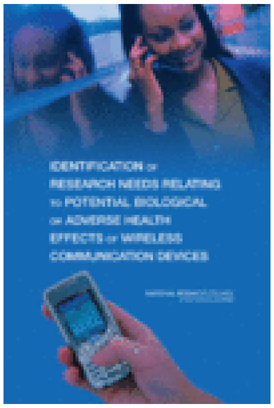


**Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communication**

Committee on Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices, National Research Council

ISBN: 0-309-11295-8, 78 pages, 6 x 9, (2008)

# IDENTIFICATION OF RESEARCH NEEDS RELATING TO POTENTIAL BIOLOGICAL OR ADVERSE HEALTH EFFECTS OF WIRELESS COMMUNICATION DEVICES

Committee on Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices

Nuclear and Radiation Studies Board

Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
*OF THE NATIONAL ACADEMIES*

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
**www.nap.edu**

**THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W. Washington, DC 20001**

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This study was supported by Award No. HHSF223200710005C between the National Academy of Sciences and the Department of Health and Human Services. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number-13: 978-0-309-11294-9
International Standard Book Number-10: 0-309-11294-X

Additional copies of this report are available from the National Academies Press, 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, http://www.nap.edu



Printed in the United States of America.

# THE NATIONAL ACADEMIES

*Advisers to the Nation on Science, Engineering, and Medicine*

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

**www.national-academies.org**

## COMMITTEE ON IDENTIFICATION OF RESEARCH NEEDS RELATING TO POTENTIAL BIOLOGICAL OR ADVERSE HEALTH EFFECTS OF WIRELESS COMMUNICATIONS DEVICES

FRANK S. BARNES (*Chair*), University of Colorado, Boulder
OM P. GANDHI, University of Utah, Salt Lake City
MAILA HIETANEN, Finnish Institute of Occupational Health, Helsinki, Finland
LEEKA KHEIFETS, University of California, Los Angeles
RÜDIGER MATTHES, Federal Office of Radiation Protection, Oberschleißheim, Germany
DAVID L. MCCORMICK, IIT Research Institute, Chicago
BERNARD VEYRET, University of Bordeaux, France

*Nuclear And Radiation Studies Board Liaison*

DANIEL KREWSKI, University of Ottawa, Ontario, Canada

*Staff*

RICK JOSTES, Study Director
NAOKO ISHIBE, Program Officer
TONI GREENLEAF, Financial and Administrative Associate
SHAUNTEÉ WHETSTONE, Program Assistant
JAMES YATES, JR., Office Assistant

# Acknowledgements

The report benefited from the contribution of the speakers and participants in the workshop. The agenda, speakers, and participants are included as appendices to the report. The committee would like to thank Rick Jostes, Shaunteé Whetstone, Toni Greenleaf, and Naoko Ishibe for helping to make the workshop a success. A special thanks to the sponsor, the U.S. Food and Drug Administration (FDA), as well.

# Reviewers

This report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council's Report Review Committee. The purposes of this review are to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following for their participation in the review of this report:

**Joel S. Bedford,** Colorado State University
**Maria Feychting,** Karolinska Institutet
**Lennart Hardell**, University Hospital
**Niels Kuster,** Foundation for Research on Information Technologies in Society (IT'IS)
**Harri Lindholm,** Finnish Institute of Occupational Health
**Gabor Mezei,** Electric Power Research Institute
**Frank S. Prato,** University of Western Ontario
**Jerome S. Puskin,** U.S. Environmental Protection Agency
**E. Van Rongen,** Health Council of the Netherlands
**Teri L. Vierima,** Resource Strategies Inc.
**Peter M. Wiedemann,** Federal Research Center

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse, nor did they see the final draft of the report before its release. The review of this report was overseen by May R. Berenbaum, University of Illinois and Daniel E. Wartenberg, University of Medicine & Dentistry of New Jersey. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the National Research Council.

# Contents

# Executive Summary

The U.S. Food and Drug Administration (FDA) of the Department of Health and Human Services asked the National Academies to organize a workshop of national and international experts to identify research needs and gaps in knowledge of biological effects and adverse health outcomes of exposure to radiofrequency (RF) energy from wireless communications devices. To accomplish this task, the National Academies appointed a seven member committee to plan the workshop.[1] Following the workshop, the committee was asked to issue a report based on the presentations and discussions at the workshop that identified research needs and current gaps in knowledge. The committee's task did not include the evaluation of health effects or the generation of recommendations relating to how the identified research needs should be met.

For the purposes of this report, the committee defines research needs as research that will increase our understanding of the potential adverse effects of RF energy on humans. Research gaps are defined as areas of research where the committee judges that scientific data that have potential value are presently lacking, but that closing of these gaps is either ongoing and results should be awaited before judgments are made on further research needs, or the gaps are not judged by the committee to be of as high a priority with respect to directly addressing health concerns at this time.

The research needs and gaps identified by the committee are presented in abbreviated form in the report Summary and in more detail in the text.

[1] Committee on Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices.

These needs and gaps are committee judgments derived from the workshop presentations and discussions, and the report does not necessarily reflect the views of the FDA, individual workshop speakers, or other workshop participants.

The committee judged that important research needs included, in order of appearance in the text, the following:

- Characterization of exposure to juveniles, children, pregnant women, and fetuses from personal wireless devices and RF fields from base station antennas.
- Characterization of radiated electromagnetic fields for typical multiple-element base station antennas and exposures to affected individuals.
- Characterization of the dosimetry of evolving antenna configurations for cell phones and text messaging devices.
- Prospective epidemiologic cohort studies of children and pregnant women.
- Epidemiologic case-control studies and childhood cancers, including brain cancer.
- Prospective epidemiologic cohort studies of adults in a general population and retrospective cohorts with medium to high occupational exposures.
- Human laboratory studies that focus on possible adverse effects on electroencephalography[2] activity and that include a sufficient number of subjects.
- Investigation of the effect of RF electromagnetic fields on neural networks.
- Evaluation of doses occurring on the microscopic level.
- Additional experimental research focused on the identification of potential biophysical and biochemical/molecular mechanisms of RF action.

[2] *Electroencephalography* is a neurological diagnostic procedure that records the changes in electrical potentials (brain waves) in various parts of the brain.

# Summary

In recent years there has been a rapid increase in the use of wireless communications devices, and a great deal of research has been carried out to investigate possible biological or human health effects resulting from the use of these devices. In a more focused initiative, the U.S. Food and Drug Administration (FDA) of the Department of Health and Human Services asked the National Academies to organize a workshop of national and international experts to identify research needs and gaps in knowledge of biological effects and adverse health outcomes of exposure to radiofrequency (RF) energy from wireless communications devices (for full statement of task see Appendix A). To accomplish this task, the National Academies appointed a seven member committee to plan the workshop (Appendix B).[1] Following the workshop, the committee was asked to issue a report based on the presentations and discussions at the workshop that identifies, in the committee's judgment, research needs and current gaps in knowledge. The committee's task did not include the evaluation of health effects or the generation of recommendations relating to how identified research needs should be met.

The requested workshop was held on August 7-9, 2007 (Appendix C). It was organized into five sessions to identify research needs and gaps in the following areas:

- dosimetry and exposure,
- epidemiology,

[1] Committee on Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices.

- human laboratory studies,
- mechanisms, and
- animal and cell biology.

A sixth session, which was held on the morning of the third day of the workshop, introduced overarching issues and solicited research needs and gaps from workshop speakers and other interested parties.

The organizing committee invited experts from 9 countries (Appendix D) to speak on research needs and gaps relating to potential biological or adverse health effects of wireless communications devices. Written contributions relating to research needs and gaps were also solicited for consideration prior to and at the workshop (individuals who submitted written contributions are listed in Appendix E).

The report contains the committee's evaluation of the workshop presentation and discussion sessions followed by the committee's identification of research needs and gaps.

## RESEARCH NEEDS AND GAPS

For the purposes of this report, the committee defines "research needs" as research that will increase our understanding of the potential adverse effects of RF energy on humans. "Research gaps" are defined as areas of research where the committee judges that scientific data that have potential value are presently lacking, but that closing of these gaps is ongoing, and results should be awaited before judgments are made on further research needs, or the gaps are not judged by the committee to be of as high a priority at this time.

To the extent possible, near-, mid-, and long-term research opportunities have been characterized as follows: the committee judged that "research needs" are near-term research opportunities. "Research gaps" that are currently being filled may result in mid-term research opportunities, depending on the outcome of the current research. "Research gaps" defined as being of lower priority with respect to directly addressing health concerns comprise possible long-term research opportunities.

Abbreviated versions of committee judgments on research needs and gaps are organized below in the Summary in order of the five sessions that comprised the first two days of the workshop. The reader is referred to the text of the report for details on research needs and gaps.

## DOSIMETRY AND EXPOSURE

### *Research Needs*

**1. There is a need to characterize exposure of juveniles, children, pregnant women, and fetuses, both for personal wireless devices (e.g., cell phones, wireless personal computers [PCs]) and for RF fields from base station antennas including gradients and variability of exposures, the environment in which devices are used, and exposures from other sources, multilateral exposures, and multiple frequencies.**

**2. Wireless networks are being built very rapidly, and many more base station antennas are being installed. A crucial research need is to characterize radiated electromagnetic fields for typical multiple-element base station antennas and for the highest radiated power conditions with measurements conducted during peak hours of the day at locations close to the antennas as well as at ground level.**

**3. The use of evolving types of antennas for hand-held cell phones and text messaging devices need to be characterized for the Specific Absorption Rates (SARs) that they deliver to different parts of the body so that this data is available for use in future epidemiologic studies.**

**4. RF exposure of the operational personnel close to multi-element newer base station antennas is unknown and could be high. These exposures need to be characterized. Also needed are dosimetric absorbed power calculations using realistic anatomic models for both men and women of different heights.**

### *Research Gaps*

Research Ongoing

1. Although several dosimetric models are currently available for children and individuals of reduced stature, a research gap remains in the further development of models of several heights for men, women, and children of various ages for use in the characterization of SAR distributions for exposures characteristic of cell phones, wireless PCs, and base stations.

Judged to Be of Lower Priority

2. Presently, there is negligible or relatively little knowledge of local SAR concentration (and likely heating) in close proximity to metallic adornments and implanted medical devices for the human body.

3. There is a need for improved exposure systems for human laboratory studies including reliable and accurate exposure assessment for designs of next generation exposure systems for human laboratory studies. Furthermore, location-dependent field strength needs to be accounted for

in the characterization of exposures. A very important consideration is the validation of results by several independent investigators so that reliable and accurate exposure assessments are available for both comparisons between systems and between laboratories.

4. There is a need for an updated survey in a properly selected sample of the U.S. population to characterize and document rapidly changing exposures to electromagnetic field strengths that would improve our knowledge of the exposure levels for the population at large, taking into account the large number of new cell phones and base stations, radio and TV stations, and a wide array of other communications devices, including a survey of measured personal exposure with information on location and activity at the time of measurement including the difference between indoor and outdoor environments.

## EPIDEMIOLOGY

**The committee identified significant research needs for a number of epidemiologic studies, particularly of children.**

### Adults

*Research Needs*

**1. Prospective Cohort Studies. A prospective cohort study will allow for the evaluation of diverse outcomes, but a very large sample size and extended follow-up is required for rare outcomes or those that occur only with very long latencies.**

**2. Occupational Cohorts with Medium to High Exposure. None of the occupational studies to date have been based on an adequate exposure assessment. Much work is needed to identify occupations with potentially high RF exposures and to characterize them.**

*Research Gaps*

Judged to Be of Lower Priority

1. Nested case-control studies of rare diseases.
2. Observational studies on subjective outcomes.

### Children

*Research Needs*

**1. Prospective Cohort Studies of Pregnancy and Childhood. Children are potentially exposed from conception through maternal wireless device use and then postnatally when they themselves become users of mobile phones.**

**2. Case-control Study of Children Mobile Phone Users and Brain Cancer. Owing to widespread use of mobile phones among children and adolescents and the possibility of relatively high exposures to the brain, investigation of the potential effects of RF fields in the development of childhood brain tumors is warranted.**

*Research Gaps*

Research Ongoing

1. Case-control studies of childhood cancer with improved exposure assessment taking into account all major fixed point sources of RF exposure (base stations, AM, FM, TV antennas, and other sources).

## HUMAN LABORATORY STUDIES

*Research Needs*

There are some significant research needs for human laboratory studies. Due to the paucity of data from identically replicated experiments,

**1. There is a need for experiments focusing on possible adverse RF effects identified by changes in electroencephalogram activity as well as a need to include an increased number of subjects.**

*Research Gaps*

Research Ongoing

1. Little or no information is available on possible neurophysiological effects developing during long-term exposure to RF fields.

2. Risks of exposure to RF fields in elderly volunteers are not well explored.

3. There is a continuing need for experiments focusing on possible adverse RF effects identified by changes in cognitive performance functions.

Judged to Be of Lower Priority

4. There is a need to conduct human volunteer studies to investigate potential health implications arising from interaction of cell phones with hearing aids and cochlear implants.

## MECHANISMS

*Research Needs*

**1. The effect of RF electromagnetic fields on neural networks is a topic needing further investigation. There are indications that neural networks are a sensitive biological target.**

**2. Evaluation of doses occurring on the microscopic level is a topic needing further investigation.**

*Research Gaps*

Research Ongoing

1. Mechanisms that can be modeled theoretically with the use of software-based nonlinear cell models that describe field-induced molecular changes. It is currently unclear if a nonlinear biological mechanism exists that could lead to demodulation effects. There is some research with respect to this question underway.

Judged to Be of Lower Priority

2. It is unclear whether low-level RF exposure can trigger effects through stimulation of cellular thermo-receptors.

3. Knowledge is lacking concerning the effects of electromagnetic fields on ion and molecular transport through the cell membrane.

## IN VIVO AND IN VITRO STUDIES IN EXPERIMENTAL MODEL SYSTEMS

*Research Needs*

**1. Additional experimental research focused on the identification of potential biophysical and biochemical/molecular mechanisms of RF action is considered to be of the highest priority.**

*Research Gaps*

Research Ongoing

1. Following completion of several large ongoing studies, a "weight-of-the-evidence" analysis can be conducted to synthesize and evaluate the entire data set. At that time, rational, informed decisions can be made concerning the value of conducting additional oncogenicity[2] studies in standard-bred laboratory animals.

2. The use of genetically engineered animals may increase the sensitivity of laboratory studies to detect weak effects, and may be particularly suitable to evaluate the possible interactions between RF fields and other agents in disease causation.

3. The overall database for RF fields and cancer would be strengthened by additional studies using multi-stage model systems for cancer in tissues (such as the brain) that have been hypothesized to be targets of RF action.

4. Although genetic toxicology studies have failed to identify potential RF health effects, additional genetic toxicology studies may be warranted should evidence of oncogenicity be identified in any of the ongoing chronic toxicity/oncogenicity bioassays of RF fields in laboratory animals, or in any future studies to be performed using genetically engineered animal models.

5. A number of potentially critical cancer-related endpoints have received only very limited study and are identified in the report text.

6. In addition to cancer-related endpoints, data gaps exist in a number of other areas of toxicology in which knowledge is needed to support a complete evaluation of the possible health effects of RF exposure; these gaps are identified in the body of the report.

[2]*Oncogenicity* is the capacity to cause tumors.

# Introduction

The U.S. Food and Drug Administration (FDA) of the Department of Health and Human Services asked the National Academies to organize a workshop of national and international experts to discuss research needs and gaps in our knowledge of the biological effects and adverse health outcomes of exposure to radiofrequency (RF) energy from wireless communications devices. Although the sponsor's main interest centers on handheld devices such as cell phones or portable home phones, base stations and antennas were also considered by the committee based on discussions with the sponsors indicating that consideration of these components would not be discouraged.

The workshop was announced on the National Academies' Current Projects site, and attendance was available to anyone interested in attending the workshop. This workshop announcement included instructions for submitting written comments for consideration at the workshop. A workshop announcement was also provided to the FDA and the Bioelectromagnetics Society for distribution as deemed appropriate, as well as to individuals who expressed an interest in the workshop.

It was clear from the presentations and discussions at the workshop that a great deal of research has been accomplished to date, but sometimes with inconsistent results. This workshop, however, was not intended to evaluate health effects, and the report based on a workshop does not assess health effects or make recommendations as to how the identified research needs should be met. The National Academies was asked to issue a report following the workshop that exclusively draws on the workshop presentations and discussions to identify current research needs and gaps in knowledge. The committee was also asked to provide its consensus findings on near-, mid-, and long-term research opportunities. The report is a committee product and does not necessarily reflect the views of the FDA, individual workshop speakers, or other workshop participants.

To organize the workshop and to identify experts to address research needs and gaps relating to potential biological or adverse health effects of wireless communications devices, the committee (Appendix B) held a workshop planning meeting on July 9-10, 2007. As a result of this planning meeting, international experts from 9 countries were invited to speak at the workshop. Written contributions on research needs and gaps for the committee's consideration were also solicited for submission prior to the workshop, which was held on August 7-9, 2007. A total of 16 written contributions were received from individuals listed in Appendix E. The speakers' presentations, panel discussions, comments from interested workshop attendees, and written contributions were considered by the committee as it developed this report.

The workshop itself was organized into six sessions (Appendix C). The first five sessions consisted of invited participants and panel discussions that identified research needs and gaps in the following areas:

- exposure and dosimetry,
- epidemiology,
- human laboratory studies,
- mechanisms, and
- animal and cell biology.

A sixth session, which was held on the morning of the third day, introduced overarching issues and solicited research needs from speakers and other interested participants. Overarching issues were determined by the committee at the workshop planning meeting held in July 2007. The purpose of the sixth session was to make sure that research needs that might reach across the disciplines were discussed and identified. The issues were thus designed to address current topics in RF research. A short introduction of each subject was made by a committee member and unrestricted input was then invited from interested parties attending the workshop. The overarching issues were as follows:

- Are there differences in health effects of short-term vs. long-term exposure?
- Are there differences between local vs. whole-body exposures?
- Can the knowledge of biological effects from current signal types and exposure patterns be extrapolated to emerging exposure scenarios?

- Are there any biological effects that are not caused by an increase in tissue temperature (nonthermal effects)?
- Does RF exposure alter (synergize, antagonize, or potentiate)[1] the biological effects of other chemical or physical agents?
- Are there differences in risk to children?
- Are there differences in risk to other subpopulations such as the elderly and individuals with underlying disease states?

These overarching issues and the general discussions that followed were factored into the committee's deliberations in developing the report. From the presentations and discussions that took place at the workshop sessions, the committee identified research needs and gaps; the selection of these research needs and gaps are committee judgments.

For the purposes of this report, the committee defines research needs as research that will increase our understanding of the potential adverse effects of RF energy on humans. Research gaps are defined as areas of research where the committee judges that scientific data that have potential value are presently lacking, but that closing of these gaps is ongoing, and results should be awaited before judgments are made on further research needs, or the gaps are not judged by the committee to be of as high a priority at this time.

To the extent possible, near-, mid-, and long-term research opportunities have been characterized as follows: the committee judged that research needs are near-term research opportunities. Gaps that are currently being filled may result in mid-term research opportunities, depending on the outcome of the current research. Gaps defined as being of lower priority with respect to directly addressing health concerns comprise possible long-term research opportunities.

[1]*Synergize:* two or more agents or forces interacting so that their combined effect is greater than the sum of their individual effects. *Antagonize:* two or more agents or forces interacting so that one agent counteracts the effect of another agent. *Potentiate:* one agent promotes or strengthens a biochemical or physiological action or effect of another agent.

# Dosimetry and Exposure

This section reports on the workshop session on radiofrequency (RF) energy,[1] dosimetry,[2] and exposure.[3]

As discussed by Dr. van Deventer at the workshop (van Deventer 2007) there is a need to characterize exposure of juveniles, children, pregnant women, and fetuses both for personal wireless devices (e.g., cell phones, wireless personal computers [PCs]) and for RF fields from base station antennas. This characterization includes taking into account gradients and variability of exposures due to the actual use of the device, the environment in which it is used, and exposures from other sources, multilateral exposures, and multiple frequencies. The data thus generated would help to define exposure ranges for various groups of exposed populations.

There is a need for reliable and accurate exposure assessment for designs of the next generation of epidemiologic studies, such as development of an index that integrates service technology and location of use (both

[1] *RF energy* includes waves with frequencies ranging from about 3000 waves per second (3 kHz) to 300 billion waves per second (300 GHz). Microwaves are a subset of radio waves that have frequencies ranging from around 300 million waves per second (300 MHz) to 300 billion waves per second (300 GHz).

[2] *RF dosimetry* is the science pertaining to coupling of RF waves, e.g., from cell phones to the human body. Because of the human anatomy, RF dosimetry must take into account the shape as well as the heterogeneity of the tissues. The unit for absorbed dose (i.e., rate of energy absorption per unit mass) is Watts/kg.

[3] *RF exposure* is the quantification of the absorbed RF energy and its distribution for the various parts of the body. The absorbed energy and its distribution within the exposed body is a function of the incident electromagnetic fields described in units of Watts/meter-squared and the spatial variation of these fields.

geographic location and whether a phone is primarily used indoors or outdoors). Towards this end, we need tissue-characterized models of children of different ages and of pregnant women for dosimetric calculations. Specific Absorbtion Rates (SARs)[4] for children are likely to be higher than for adults, both for cell phones and for base station exposures, due to the fact that the exposure frequency is closer to the whole-body resonance frequency for shorter individuals such as children (ANSI 1982; Gandhi 1979; Wang et al. 2006; Hirata et al. 2007). Better characterization of SARs for children of various age groups is, therefore, needed. Furthermore, models are not presently adequate for men and women of various heights and for children of various ages.

## BASE STATIONS

Wireless networks are being built very rapidly, and many more base station antennas are being installed. Maintenance personnel may be exposed to fairly high electromagnetic fields emanating from base station antennas[5] unless all of the typically four to six antennas mounted on the base station are turned off. For all of the base station antennas, the radiated power is on the order of several tens of watts, with higher powers being radiated at peak hours of the day. Though not as well characterized, particularly for multiple co-located base station antennas, the radiated RF fields for rooftops near base stations may also be fairly high. The quantification of SAR distributions from base stations is fairly minimal and those distributions are of concern for professionals involved in maintenance of base stations, building/roof maintenance personnel, and members of the public that live in close proximity to the antennas. There are also subpopulations among the employees, which might be exposed to greater amounts of RF energy than the average population. The characterization of these subpopulations is important.

Thus, the interest in base station exposures close to the antennas is driven by the potential health effects on antenna repair professionals and building/roof maintenance workers from relatively high, acute exposures, but the interest in exposures for members of the public that live in close proximity to the antennas or for the public at the ground level at larger distances is motivated by the need to address public concern about very low

[4] *Specific Absorption Rate* (SAR) is a measure of the rate at which radiofrequency (RF) energy is absorbed by the body when exposed to an RF electromagnetic field. The most common use is in relation to cellular telephones.

[5] Base station antennas mounted on rooftops, on poles, or other elevated positions are the important intermediaries for cell phone communications.

level, chronic exposures that are in fact similar to those from existing TV and radio antennas albeit at different frequencies.

Most of the reported studies to date have involved one base station antenna and have used mostly homogeneous models, often of simplified circular or rectangular cross sections of the exposed human. One study involving a heterogeneous, anatomically based model consisting of diverse constituents, but still assuming a single antenna rather than typical arrangements of four to six antennas, is given in Gandhi and Lam (2003). In other words, the studies to date do not pertain to the commonly used multiple-element base station radiators. Also, unlike highly localized cell phone RF energy deposition, the base station exposures involve much, if not all, of the body and would have slightly different radiator origins (for multi-element base stations) and may be multi-frequency as well, particularly if several different-frequency base station antennas are co-located. Furthermore, because of the whole-body resonance[6] phenomenon, the SAR is likely to be higher for shorter individuals due to the closeness of the frequency/frequencies of exposure to the whole-body resonance frequency. In addition to the rapid growth in the number of base stations since 1990, there has also been growth in other sources of RF radiation from cordless phones, wireless computer communications, and other communications systems. The last general survey of RF levels in U.S. cities was during the 1970s, and an updated survey of RF intensities would be useful background for future epidemiologic studies. There are many indoor wireless systems as well as cell phones, which are used both indoors and outdoors. Measurements of the differences in the exposures generated by the use of these devices in these environments will be of value in determining if there are any health effects resulting from exposures to low levels and intermittent sources of RF radiation.

## MOBILE PHONES

The use of evolving types of antennas for cell phones and text messaging devices needs to be characterized for the SARs that they deliver to different parts of the body so that this data is available for use in future epidemiologic studies. A great deal of research has been done by many laboratories worldwide to understand coupling of RF energy irradiation from cell phone antennas to the human head. For most of these studies, the

[6] *Whole-body resonance*: It has been shown that each individual absorbs maximum energy from incident RF fields at frequencies that are higher for shorter individuals. Furthermore the SAR at this resonance frequency is increasingly higher for shorter individuals (Gandhi 1979). As the absorbed energy diminishes inversely with frequency in the post-resonance region, it is still quite high for the shorter individuals at base station frequencies because of the relative proximity of these frequencies to the resonance frequencies.

researchers have assumed that cell phones are held against one of the ears, and studies have used a variety of anatomically based models. Cell phones were assumed to have pull-out linear rod antennas with dimensions on the order of several centimeters. However, most of the recent telephones use built-in antennas of various shapes for which additional published information is needed.

The published results on pull-out linear rod antennas are generally in agreement in that the RF energy coupled to the human head is the highest for the ear and for a limited volume (approximately 3 × 3 × 3 cm) of the brain proximal to the cell phone (IEEE 1996). As expected, the penetration of the coupled electromagnetic fields[7] into the brain is shallow (approximately 2 cm) at higher frequencies (i.e., 1800-1900 MHz). For cell phones held against the ear, the SAR drops off rapidly for the regions of the brain away from the antenna and is negligible for the rest of the human body except for the hand.

Wireless technology is leading to devices such as wireless PCs, handheld devices used for video calls, and other handheld devices for text messaging. In their typical usage, the antennas are closer to the hand or other parts of the body. SAR distributions for these newer devices have been obtained using homogeneous liquid-filled flat phantom models. Though these models are reasonably accurate to get the 1 or 10 Watts/kg average SAR needed for safety compliance testing, they are incapable of providing detailed SAR distributions because of lack of detailed anatomical features, e.g., for the hand or the human lap or parts of the body close to the devices. Additionally, such models cannot resolve the detailed RF field distribution at the cellular and subcellular levels. Given a set of anatomical data, the RF field distributions can be modeled and estimates can be made of the effects of various wave forms and carrier frequencies. An important research gap is the lack of models of several heights for men, women, and children of various ages for use in the characterization of SAR distributions for exposures characteristic of cell phones, wireless PCs, and base stations.

Presently, there is negligible or relatively little knowledge of local SAR concentration (and likely heating) in close proximity to metallic adornments and implanted medical devices for the human body. Examples include metal rim glasses, earrings, and various prostheses (e.g., hearing aids, cochlear implants, cardiac pacemakers). Research is therefore lacking to quantify the enhanced SARs close to metallic implants and external metallic adornments.

[7]If either the electric or magnetic field has a time dependence, then both fields must be considered together as a coupled electromagnetic field using Maxwell's equations.

## LABORATORY EXPOSURE SYSTEMS

There is a need for improved exposure systems for human laboratory studies. Furthermore, location-dependent field strength needs to be accounted for in the characterization of exposures. Most of the present-day exposure systems used in laboratory studies focus on the exposure of the head. Though exposures to the head are relevant for most cell phone exposures, whole-body exposures due to base stations are a research need. The laboratory exposure systems also need to include ELF[8] and pertinent modulation protocols.[9]

There is a need for reliable and accurate exposure assessment for designing the next generation of epidemiologic studies, such as development of an index that integrates service technology and location of use (both geographic location and whether a phone is primarily used indoors or outdoors). For human laboratory studies there has been considerable effort to quantify the uncertainties of the different methods used in dosimetry. However, there is little information about the overall accuracy of the dosimetric approaches with respect to reality and variability. The accuracy of dosimetric approaches is particularly important as well as the validation of results by several independent investigators to establish SAR variability.

The committee's evaluation of presentations and discussions at the workshop has resulted in the identification of the following research needs and gaps.

### *Research Needs*

1. **There is a need to characterize exposure of juveniles, children, pregnant women, and fetuses both for personal wireless devices (e.g., cell phones, wireless PCs) and for RF fields from base station antennas including gradients and variability of exposures, the environment in which devices are used, and exposures from other sources, multilateral exposures, and multiple frequencies.** The data thus generated would help to define exposure ranges for various groups of exposed populations.

2. **Wireless networks are being built very rapidly, and many more base station antennas are being installed. A crucial research need is to characterize radiated electromagnetic fields for typical multiple-element (four to six elements) base station antennas for the highest radiated power conditions and with measurements conducted during peak hours of the day at locations close to the antennas as well as at ground level. A study of the wire-**

[8]*ELF:* Extremely low frequency fields, such as the 50 and 60 Hz power frequency fields used in Europe and the United States, respectively.

[9]Some commonly used modulation protocols are TDMA (time division multiple access) and CDMA (code division multiple access).

**less RF fields in a properly selected sample of the population is needed to characterize and document rapidly changing exposures.**

**3. The use of evolving types of antennas for hand-held cell phones and text messaging devices need to be characterized for the SARs that they deliver to different parts of the body so that this data is available for use in future epidemiologic studies.**

**4. RF exposure of the operational personnel close to newer multi-element base station antennas is unknown and could be high. These exposures need to be characterized. Also needed are dosimetric absorbed power calculations using realistic anatomic models for individuals, including both men and women of different heights.**

*Research Gaps*

Research Ongoing

1. Although several models are available for children and individuals of reduced stature, a research gap remains in the further development of models of several heights for men, women, and children of various ages for use in the characterization of SAR distributions for exposures characteristic of cell phones, wireless PCs, and base stations.

Judged to Be of Lower Priority

2. Presently, there is negligible or relatively little knowledge of local SAR concentration (and likely heating) in close proximity to metallic adornments and implanted medical devices for the human body.

3. There is a need for improved exposure systems for human laboratory studies including reliable and accurate exposure assessment for designs of next generation exposure systems for human laboratory studies. Furthermore, location-dependent field strength needs to be accounted for in the characterization of exposures. A very important consideration is the validation of results by several independent investigators so that reliable and accurate exposure assessments are available for both comparisons between systems and between laboratories.

4. An updated survey of the electromagnetic field strengths in the U.S. would improve our knowledge of the exposure levels for the population at large. This survey should take into account the large number of new cell phone stations, radio stations, and TV stations and a wide array of other communications devices. It would include a survey of the difference between indoor and outdoor environments.

# Epidemiology

The second session of the workshop focused on epidemiologic studies. The following sections are organized into cancer and noncancer effects, and effects in children.

Epidemiologic studies are of primary importance in health risk assessment, because they are able to provide direct information on the health of people exposed to an agent. While epidemiologic investigations are difficult to conduct and easy to criticize, they offer unique advantages over experimental models. In particular, epidemiologic studies permit for associations between an environmental exposure, under actual rather than artificial conditions, and a health outcome to be evaluated in human populations. Moreover, because epidemiologic research is conducted in natural settings, the joint influence of multiple factors on disease occurrence can be studied, while taking into account an individual's susceptibility. Equally important, extrapolation from high doses to low doses is not necessary because epidemiologic studies examine a wide range of exposures at relevant doses. However, epidemiologic studies may be affected by bias,[1] confounding,[2] and exposure misclassification.[3] A large amount of exposure misclassification is likely to be present for radiofrequency (RF) exposure. Furthermore,

[1] *Bias* is any trend in the collection, analysis, interpretation, publication, or review of data that can lead to conclusions that are systematically different from the truth. Types of bias include recall and selection.

[2] *Confounding* occurs when an observed association between an exposure and disease is distorted by other risk factors for the disease that are also associated with exposure.

[3] *Misclassification* is inaccuracies in how subjects are categorized by exposure or disease status.

large studies are needed to have enough statistical power to detect effects when exposures and outcomes are rare. Thus, while the observational nature of the epidemiologic studies makes them difficult to conduct and interpret, they remain indispensable by providing direct information on the health of people exposed to an agent.

## CANCER EFFECTS

Recent concerns about possible health effects of exposure to RF radiation from cellular phones have centered on brain cancer (Krewski 2007), and a series of epidemiologic studies looking at the association between cellular phone use and malignant and benign brain tumors, as well as salivary gland tumors, have been published since 1999 (Johansen et al. 2001; Lonn 2004; Shoemaker et al. 2005; Schuz et al. 2006; Hardell et al. 2006; Lahkola 2007). The majority of these have been case-control studies.[4] Limitations of these studies have included inclusion of only a small number of heavy users, inability to account for a sufficiently long latency[5] period, differential participation by cases and controls according to history of cellular phone use, inclusion of both prevalent and incident cases,[6] and relatively crude exposure assessment. All of these case-control studies relied on self-reported histories of cellular phone use, which can be prone to both random and systematic errors.[7] The latter could occur if cases or their proxies tended to over-report cellular phone use relative to controls or if tumor laterality[8] influenced reported laterality of phone use. It also is possible that cognitive impairment would cause brain cancer cases to incorrectly report phone use.

Analyses conducted as part of the INTERPHONE study, a multi-center international case-control study of brain and parotid gland tumors, point to selection bias[9] due to likely under-enrollment of nonexposed controls,

---

[4]A *case-control study* is a type of observational study in which subjects are selected on the basis of whether they have or do not have a disease under investigation. Characteristics such as previous exposure are then compared between cases and controls.

[5]*Latency* is the period of subclinical disease following exposure that ends with the onset of disease.

[6]*Prevalence* is the number or proportion of cases or events or conditions present in a given population. Incident cases are those who are newly diagnosed with the disease of interest.

[7]*Random errors* vary in a nonreproducible way around a limiting mean. These errors can be treated statistically by use of the laws of probability. *Systematic errors* are reproducible and tend to bias a result in one direction. Their causes can be assigned, at least in principle, and they can have constant and variable components.

[8]*Tumor laterality* is the preference in location of tumor in one portion of the body over other locations in the body.

[9]*Selection bias* occurs when the association that is observed among those who participate in a study is different from what would have been observed because individuals who were eligible to participate refused or were not selected.

which would tend to bias estimates of the odds ratio downward (Vrijheid et al. 2006). Random errors in reported use of cellular phones also could obscure a small increase in risk. In the simulation study based on different assumptions about random and systematic errors using preliminary data of a study on short-term recall of mobile phone use among healthy volunteers, sensitivity analyses indicated that random errors in recall were likely to outweigh plausible systematic errors in recall that can lead to a large under-estimation, if there is a true risk, in the risk of brain cancer associated with use of wireless communication devices (Vrijheid et al. 2006). The pending results of the INTERPHONE study, by far the largest case-control study of head and neck tumors to date, are likely to have a major influence on the direction and scope of future research concerning the use of cellular phones and cancer.

An international collaborative study with prospective follow-up of mobile phone use is being launched in Europe. A key advantage of cohort studies[10] is the ability to evaluate multiple outcomes, providing the opportunity for a more comprehensive assessment of possible health risks. In addition, more accurate exposure data may be obtained because recall of exposure information would be independent of the outcome of interest and the self-reported mobile phone use could be complemented more readily with information from mobile service providers. Furthermore, selection bias should not be an issue as it can be in a case-control study. Sufficiently long exposure and follow-up would allow for the detection of effects that occur with a latency of several years. Additionally, it might be possible to collect data to evaluate dose-response relationships in a prospective cohort study. Mortality is probably inadequate as the sole measure of effect and incidence[11] could also be included.

Occupational studies[12] have been performed over a longer time period, but the exposure frequencies may not always be relevant for an assessment of effects at frequencies of interest from wireless communication devices, and we are only beginning to measure and learn about RF exposures in various occupations. The most extensive literature addresses brain tumors and leukemia, but also of note are cancers of the breast (Tynes et al. 1996; Morgan et al. 2000), testis (Hayes et al. 1990), lung (Armstrong et al. 1994; Groves et al. 2002), and uveal melanoma[13] (Stang et al. 2001). These studies have several methodological weaknesses related to the fact that none

[10]A *cohort study* is a type of epidemiologic study where a group of individuals are followed over time to assess the occurrence of a given disease or condition. Enrollment into the study is based on exposure characteristics or membership in a group.

[11]*Incidence* is a measure of disease occurrence that quantifies the number of new cases of a disease that develop in a population of individuals at risk during a specified time period.

[12]*Occupational studies* are studies of workers.

[13]*Uveal melanoma* is cancer of the eye.

of the studies measured RF exposures. The included occupations did not necessarily represent truly highly exposed occupations. Another weakness is that exposure classification has often been based on a single job title. In addition, limited control of confounding, if any, has been made.

Evaluation of effects and adjustment for exposure measurement error and selection bias in case-control studies is needed. By better characterizing exposure measurement error and evaluating the magnitude of selection bias, such information may be used to adjust for exposure misclassification in existing and future studies.

Several ecologic studies[14] (Hocking et al. 1996; McKenzie et al. 1998) have examined cancer risk, including risk of childhood leukemia, among populations living in proximity to radio and television broadcast towers. Often driven by a previously identified cluster, these analyses are based simply on distance from the source and often include an extremely small number of cases. Such studies have been mostly uninformative. More rigorous investigations might be feasible with a development of new instruments capable of capturing personal RF exposures.

Furthermore, in addition to the rapid growth in the number of base stations, there has been a growth of other sources of RF radiation from cordless phones and wireless systems. The last general survey of RF levels in U.S. cities was conducted in the 1970s (Tell and Mantiply 1980), and an updated survey of RF intensities would be useful background for future epidemiologic studies. Measurements of the differences in the exposures generated by the use of cell phones and other wireless systems will be of value in determining if there are any health effects resulting from exposures to low levels and/or intermittent sources of RF radiation.

## NONCANCER HEALTH EFFECTS

Few studies have been conducted on health effects other than cancer risk of RF electromagnetic fields from wireless communication devices (Auvinen 2007). The existing studies have been small and have methodological limitations such as lack of rigorous exposure assessment, inadequate control of confounding, and cross-sectional design. Exposure settings have included mobile phone use, residence close to base stations, and occupational exposures (broadcasting). The health endpoints evaluated include reproductive effects, cardiovascular health (Morgan et al. 2000; Groves et al. 2002), and nonspecific symptoms such as headache, sleep disturbances, fatigue, and depressed mood (Chia et al. 2000; Sandstrom et al. 2001). Several reports of increased prevalence of symptoms among

[14] *Ecologic studies* contain only information on population averages and lack joint distributions of individual-level variables.

subjects exposed to communication devices have been published, but the quality of the research is generally low. At present, the knowledge base of health effects other than cancer is grossly inadequate.

Due to lack of knowledge on possible mechanisms and the wide range of potential effects, assessment of research needs cannot be very specific. Little indication to guide future efforts is available from other fields of research related to wireless communications devices (in vivo studies, animal studies, or laboratory studies of volunteers). Thus, multi-endpoint studies are needed, and in this case a cohort approach of both children and adults is most suitable. In addition, there is the possibility of obtaining more accurate exposure data, which is important considering how rapidly wireless technology is changing in both exposure characteristics (e.g., frequencies and modulation) and usage pattern (e.g., phone use vs. text messaging or web surfing). The following outcomes are of particular interest: cancer, cardiovascular, neurological, neurodegenerative, and cerebrovascular diseases; and reproductive, behavioural, cognitive, neurophysiologic, and neuropsychological effects, including headaches, sleep disturbances, tinnitus,[15] psychiatric disorders, and well-being (health-related quality of life).

## Children

With the rapid advances in technologies and communications utilizing RF fields, children are increasingly exposed to RF energy at earlier ages (starting at age 6 or before). Environmental exposures could be particularly harmful to children because of their vulnerability during periods of development before and after birth. Although it is unknown whether children are more susceptible to RF exposures, they may be at increased risk because of developing organ and tissue systems, particularly of the nervous system (Kheifets et al. 2005). In addition, they may have a greater specific absorption rate (SAR) and higher absorption of RF energy at frequencies utilized in wireless communications devices and greater RF penetration relative to head size. Finally, the current generation of children will experience a longer period of exposure to RF fields from mobile phone use than adults since they started using mobile phones at an early age and are likely to continue to use them. Data from the INTERPHONE study show that both the prevalence of regular mobile phone users and daily use were highest in the younger age groups (Cardis et al. 2007). Moreover, several recent trends (such as increased popularity, reduced price, and advertising to children) have led to increased mobile phone use among children. A steep increase in mobile phone ownership among children has been reported in

[15] *Tinnitus* is ringing of the ears.

several surveys. In spite of this, there is virtually no relevant epidemiology at present that examines health effects in children.

Children are potentially exposed from conception through maternal wireless device use and then postnatally when they themselves become users of mobile phones. Both short-term and long-term health consequences of mobile phone use can be efficiently studied by adding information on the mobile phone use to the existing birth cohorts using a life course approach. Cognitive and behavioral effects are of particular importance and can be evaluated in the near term.

Owing to widespread use of mobile phones among children and adolescents and the possibility of relatively high exposures to the brain, investigation of the potential effects of RF fields in the development of childhood brain tumors is warranted. Brain cancer is an important endpoint to study but is rare in children and so a cohort study is unlikely to be feasible.

There is at present a lack of information concerning the health effects associated with living in close proximity to base stations. Epidemiologic studies of mobile phone base stations present unique challenges that need to be addressed to make such studies rigorous. One particular difficulty in a study of populations near transmitters such as TV, radio, and base stations, with both residential exposure and cell phone use, is the development of accurate indexes of exposure that are closely correlated to the exposures that a person receives. Assuming a nonspecific effect from RF exposure implies that in an epidemiologic study all major RF sources should be evaluated (i.e., from both base stations and TV and radio towers as exposure from these sources are whole body and of similar magnitude; additionally, exposure from one's own cell phone use should be considered). Further investigation into improved measurements is a critical step in better capturing exposure data from these sources and in determining the feasibility of epidemiologic studies of children living in the vicinity of these sources.

The committee's evaluation of presentations and discussions at the workshop has resulted in the identification of the following research needs and gaps.

## Adults

*Research Needs*

**1. Prospective Cohort Studies. A prospective cohort study will allow for the evaluation of diverse outcomes, but a very large sample size and extended follow-up is required for rare outcomes or those that occur only with very long latencies.**

**2. Occupational Cohorts with Medium to High Exposure. None of the occupational studies to date have been based on an adequate exposure**

**assessment. Much work is needed to identify occupations with potentially high RF exposures and to characterize them.** Among the particular findings in need of follow-up are uveal cancer, leukemia, lung, breast, testicular cancers, and sperm quality. If feasible, epidemiologic studies could focus on the health effects of potential RF exposures at high levels that might occur in a few workplace tasks (e.g., antenna construction and maintenance). In addition, several groups of firefighters have expressed concerns about their exposure from base stations located in firehouses and possible exposure to antennas on the fire trucks. A feasibility study might be useful in determining whether these groups have a sufficient exposure range and if an informative study is feasible.

*Research Gaps*

Judged to Be of Lower Priority

**1. Case-control Studies of Rare Diseases.** For rare diseases, such as adult leukemia, non-Hodgkin lymphoma and neurodegenerative diseases, additional case-control studies may be justified as a cohort study will likely not have sufficient statistical power. Such case-control studies would better characterize exposure and try to adjust for exposure measurement error and selection bias as needed.

**2. Observational Studies on Subjective Outcomes.**[16] Subjective outcomes from long-term exposures can be addressed in appropriately designed, observational studies (e.g., prospective cohort study) that include provisions for avoiding or minimizing reporting and selection and misclassification biases.

## Children

*Research Needs*

**1. Prospective Cohort Studies of Pregnancy and Childhood. Children are potentially exposed from conception through maternal wireless device use and then postnatally when they themselves become users of mobile phones.** Both short-term and long-term health consequences of mobile phone use can be efficiently studied by adding information on the mobile phone use to the existing birth cohorts using a life course approach. Cognitive and behavioral effects are of particular importance and can be evaluated in the near term.

[16]*Subjective outcomes* are outcomes or symptoms that are difficult to quantify objectively (e.g., pain, headaches, sleep disturbances).

**2. Case-control Study of Children Mobile Phone Users and Brain Cancer. Owing to widespread use of mobile phones among children and adolescents and the possibility of relatively high exposures to the brain, investigation of the potential effects of RF fields in the development of childhood brain tumors is warranted.** Brain cancer is an important endpoint to study but is rare in children and so a cohort study is unlikely to be feasible.

*Research Gaps*

Research Ongoing

1. Case-control studies on childhood cancer with improved exposure assessment taking into account all major fixed point sources of RF exposure (base stations, AM, FM, TV antennas, and other sources). There is at present a lack of information concerning the health effects associated with living in close proximity to base stations. Epidemiologic studies of mobile phone base stations present unique challenges that need to be addressed to make such studies rigorous.

# Human Laboratory Studies

The third session of the workshop focused on human laboratory studies. Human laboratory studies of radiofrequency (RF) exposure investigate the effects of RF exposure to humans in a controlled laboratory environment to determine potential RF effects on relevant biological endpoints including changes in electroencephalogram (EEG) amplitudes, increase in blood pressure, sleep disturbances, cardiac arrhythmia, changes in cognitive performance, and headaches. This report section is organized into neurophysiological and cognitive effects, effects on the ear and hearing, effects on heart rate and blood pressure, and subjective symptoms and electromagnetic hypersensitivity (EHS).

## NEUROPHYSIOLOGICAL AND COGNITIVE EFFECTS

In spite of the large number of investigations, RF-induced neurophysiological effects need further study. While several studies have focused on spectral power of EEG, regional cerebral blood flow (rCBF),[1] and event-related (evoked) potentials (ERP),[2] most of the present data are collected by investigations evaluating acute effects on healthy adults during short

[1] *Cerebral blood flow* (CBF) is the blood supply to the brain in a given time, being about 15 percent of the cardiac output. An increase or decrease in normal CBF will cause an increase or decrease in cerebral arterial blood volume because of arterial dilatation or constriction.

[2] An *event-related potential* (ERP) is any stereotyped electrophysiological response to an internal or external stimulus. More simply, it is any measured brain response that is directly the result of a thought or perception.

exposures to RF fields. Dosimetric measurements for different cortical functional subregions can be conducted inside a head phantom filled with liquid having tissue-equivalent dielectric properties. A calibrated RF field scanning probe, moved by a robotic arm, records the spatial values of electric field strengths and Specific Absorption Rates (SARs) within cubic volumes in the head phantom.

It is generally recognized that the interpretation of EEG findings is difficult because of the high intra-individual variability in attention and waking state of volunteers. Some of the waking EEG studies reveal an enhancement of cortical activity, as measured by the increase of spectral power in the alpha band[3] during RF exposure. Also, the most convincing effects of RF exposure on the sleep EEG indicate an increase of the power of the alpha waves, while studies on ERPs have given mixed and inconclusive results (Hamblin and Wood, 2002; Cook et al. 2006).

For other spectral ranges,[4] reduction of beta band, attenuation in the theta activity, and increase of gamma response have been reported, as well as reduced amplitude and latency of N100 waves[5] and an increased P300 latency.[6] However, these findings could not be replicated with an experiment that had more statistical power (Hamblin et al. 2006). The inconsistency with the previous studies was attributed to the small sample size or the lack of a double blind protocol of the previous study.

Cognitive performance was assessed using several cognitive tasks, but no statistically significant effects were found on task performances in a recent study on effects on cognitive performance of exposure to 888 MHz signals using 168 volunteers (Russo et al. 2006). Another comprehensive study focused on cognitive performance of 120 subjects exposed to 900 MHz mobile phones (Keetley et al. 2006). Cognitive performance was assessed using eight cognitive tests. After adjusting for gender, age and education, simple and choice reaction times showed significant impairment, whereas performance on the trail-making task,[7] which involves working memory, significantly improved.

---

[3]The *alpha band* is the spectral component in the EEG signal, which falls between 8-13 Hz.

[4]EEG has usually been described in terms of frequency bands: GAMMA (greater than 30 Hz), BETA (13-30 Hz), ALPHA (8-13 Hz), THETA (4-8 Hz), and DELTA (less than 4 Hz).

[5]*N100* is an ERP component, characterized as a negative deflection in voltage, peaking approximately 100 ms after the stimulus. Anomalies in N100 may give rise to cognitive deficits (i.e., impairments of memory and learning abilities).

[6]*P300* is an ERP potential component, characterized as a positive deflection in voltage, peaking approximately 300 ms after the stimulus.

[7]This test consists of two parts, A and B. Part A consists of encircled numbers from 1 to 25 spread across a sheet of paper. The object of the test is for the subject to connect the numbers in order, beginning with 1 and ending with 25, whereas Part B requires the subject to connect numbers and letters in an alternating pattern (1-A-2-B-3-C, etc.), both in as little time as possible.

## EFFECTS ON THE EAR AND HEARING

Because of the close proximity of mobile phones to human ears, the area around the ear receives the highest RF exposure, and a lot of interest has focused on possible effects on auditory perception or on acoustic evoked potentials.[8] However, in the majority of experiments on hearing threshold levels or transient evoked otoacoustic emissions,[9] no significant effects have been reported. Accordingly, no effects of RF exposure on auditory functions of the cochlea or auditory brainstem responses have been found by several research groups (Pau et al. 2005; Sievert et al. 2005; Parazzini et al. 2005).

While there is no evidence on adverse effects on hearing, there are anecdotal reports on interaction of cell phones with hearing aids and cochlear implants. At present, however, there are very few experimental data from human volunteer studies concerning health problems with auditory prostheses.

## EFFECTS ON HEART RATE AND BLOOD PRESSURE

Acute changes in the blood pressure and in other cardiophysiological parameters during RF exposure have been studied using healthy adult volunteers. In a study of 32 volunteers, an extensive set of test conditions including controlled and spontaneous breathing, head-up tilt table test, and deep breathing tests was applied during real and sham exposure (Tahvanainen et al. 2004). The results indicated no statistically significant effects on heart rate or blood pressure. Also a later comprehensive study with 125 volunteers concluded that RF exposure from cellular phones does not cause noticeable effects on heart rate regulation in healthy adults (Barker et al. 2007).

Although there is no clear evidence concerning the negative cardiovascular, inflammatory, or respiratory health effects of the electromagnetic field (EMF) produced by wireless communications tools at the macrophysiological level, further studies focusing on the early phase of potentially harmful changes are needed. The new techniques focusing on endothelial dysfunction or prolonged oxidative stress have not been extensively used

[8]*Evoked potentials* are brain reactions on stimulus with amplitude much lower than EEG voltage measured during regular brain activity. While different evoked potentials occur as a result of different stimuli, acoustic evoked potentials (AEP) are a result of acoustic stimuli.

[9]An *otoacoustic emission* (OAE) is a sound that is generated from within the inner ear. Broadly speaking, there are two types of otoacoustic emissions: Spontaneous Otoacoustic Emissions (SOAEs) and Evoked Otoacoustic Emissions (EOAEs). As their names suggest, SOAEs arise spontaneously and EOAEs require an evoking stimulus.

in the human studies. Also, the rapidly developing salivary biochemical analysis techniques offer new possibilities.

## SUBJECTIVE SYMPTOMS AND ELECTROMAGNETIC HYPERSENSITIVITY

During recent years, numerous individuals have reported a variety of health problems that they relate to exposure to RF fields from mobile phones. While some perceive only mild symptoms and react by avoiding phones, others are so severely affected that they change their entire lifestyle. This reported sensitivity has been generally termed "electromagnetic hypersensitivity" or EHS (WHO 2005).

A number of studies have been conducted where EHS individuals were exposed to RF fields similar to those emitted by cellular phones. In one provocation study,[10] 20 EHS volunteers were exposed to cellular phone signals, which they attributed to the cause of their symptoms (Hietanen et al. 2002). The aim was to elicit symptoms under controlled conditions with low-background fields. The number of reported symptoms was higher during sham exposure than during RF exposure, which could have been due to higher postural and mental tension at the beginning of the experiment when subjects were not yet adapted to the experimental conditions. In another study, persons with self-reported sensitivity to mobile phone signals did not react to RF exposure with any increased severity of perceived symptoms (Rubin et al. 2006). Hence there is little support in the research community for the perception that RF fields can be related to EHS or symptoms (Roosli 2007).

The conclusion of the Fact Sheet on EHS published by the World Health Organization's (WHO's) EMF project is that "EHS is characterized by a variety of non-specific symptoms that differ from individual to individual. The symptoms are certainly real and can vary widely in their severity. Whatever its cause, EHS can be a disabling problem for the affected individual. EHS has no clear diagnostic criteria and there is no scientific basis to link EHS symptoms to EMF exposure. Further, EHS is not a medical diagnosis, nor is it clear that it represents a single medical problem" (WHO 2005).

The committee's evaluation of presentations and discussions at the workshop has resulted in the identification of research needs and gaps. Because of the paucity of data from identically replicated experiments, any future studies would benefit from experiments focusing on possible adverse effects on EEG activity, as well as on cognitive performance functions, and should include an increased number of subjects (Croft 2007).

[10] An investigation into the basis of symptoms attributed to RF emissions.

For further research, the workshop attendees noted the following important considerations:

- appropriate exposure regimes,
- multi-center collaborations using identical research protocols,
- large sample sizes, and
- reliable EEG analysis techniques.

In addition, most human studies have examined healthy young adults, a group not necessarily representing the most susceptible part of the population. Therefore, future research needs to include children, the elderly, and people with underlying diseases. While the basic thermoregulatory physiology of healthy people in relation to external heat stress and internal heat load generated by RF radiation is well known, elderly people may be particularly vulnerable to the effects of heat stress (coronary and cerebral thrombosis); therefore, a gap exists in the study of this population.

Current research gaps include little existing information about neurophysiological changes during heavy (occupational) use of cellular phones for several years. A second gap is that no studies using elderly volunteers are available, but could be performed. Finally, there is a continuing need for experiments focusing on possible adverse RF effects identified by changes in cognitive performance functions.

### *Research Needs*

There are some considerable research needs for human laboratory studies. Due to the paucity of data from identically replicated experiments,

**1. There is a need for experiments focusing on possible adverse RF effects identified by changes in EEG activity, as well as a need to include a larger number of subjects.**

### *Research Gaps*

Research Ongoing

1. Little or no information is available on possible neurophysiologic effects developing during long-term exposure to RF fields.
2. Risks of exposure to RF fields in elderly volunteers are not well explored.
3. There is a continuing need for experiments focusing on possible adverse RF effects identified by changes in cognitive performance functions.

Judged to Be of Lower Priority

4. Because the use of cell phones by individuals with auditory prostheses is increasing, there is a need to conduct human volunteer studies to investigate potential health implications arising from interaction of cell phones with hearing aids and cochlear implants.

# Mechanisms

Knowledge of the basic interaction mechanisms of radiofrequency (RF) electromagnetic fields (EMFs) with cellular and subcellular (molecular) structures provides a basis for extrapolation of existing knowledge to future technologies and exposure conditions. Thus, research on interaction mechanisms is an important topic and a relevant part of most research programs worldwide. In Europe and the United States, such research has been ongoing for decades.

Some of the interaction mechanisms that have been identified so far are well understood and widely accepted. Those include mechanisms that lead to thermal effects in biological tissues and forces exerted at high field strengths that result in dielectrophoresis,[1] electroporation,[2] and pearl chain formation[3] of cells (Schwan 1982, 1985; Holzapfel et al. 1982). The responses of cells to elevated temperature are well documented and seem to be independent from the heating source. The electroporation effects are technically used, for example in pharmacology and for basic scientific research in the integration of external DNA into cells. For wireless communication devices electroporation is not relevant as it becomes significant

[1]*Dielectrophoresis* is defined as the lateral motion imparted on uncharged particles as a result of polarization induced by nonuniform electric fields.

[2]*Electroporation* is a mechanical method used to introduce polar molecules into a host cell through the cell membrane. In this procedure, a large electric pulse temporarily disturbs the phospholipid bilayer, allowing molecules like DNA to pass into the cell.

[3]Chains of living or nonliving particles (pearl chains) form along the lines of force of electromagnetic fields (including RF fields).

only at very high field strengths. The minimum RF signal that can modify the transport of ions and molecules is an open question.

The basic question still under debate is whether there are other interaction mechanisms of low-intensity RF electromagnetic fields that could have health consequences. Of particular interest is the possible existence of health effects that occur due to the accumulation of multiple, long-term, low-intensity RF exposures.

Currently, the most appropriate ways to answer these basic questions include the use of biophysical[4] (theoretical), biochemical, and biological approaches. At the physical and chemical levels, the prime goal is to identify a candidate mechanism that could overcome the various sources of "noise" in the biological system.

From the biochemical and biological perspective, two approaches were suggested at the workshop to identify mechanisms that may be operating at low exposures:

- Successive- or multiple-hypothesis testing based on hazard mechanisms or stress responses that are relevant for cancer (Roti Roti 2007). The pitfall of this approach seems to be that the number of parameters to be tested is high and not all parameters are known.
- The use of high-throughput screening methods (Leszczynski 2007) such as genomics,[5] proteomics,[6] metabolomics,[7] and others not yet developed (the so called "-omics"). Such methods have already been used in EMF research programs. The pitfall of these methods is the very high number of reactions that might be detected. Many of those reactions might be of no relevance or be false positives. Thus all findings need to be validated using complementary methods.

From the biophysical perspective a series of mechanisms has been suggested by various investigators. Those mechanisms include but are not limited to:

---

[4]A *biophysical approach* is one that applies physical principles and methods to biological problems.

[5]*Genomics* is a branch of biotechnology concerned with applying the techniques of genetics and molecular biology to the genetic mapping and DNA sequencing of sets of genes or the complete genomes of selected organisms using high-speed methods.

[6]*Proteomics* is a branch of biotechnology concerned with applying the techniques of molecular biology, biochemistry, and genetics to analyzing the structure, function, and interactions of the proteins produced by the genes of a particular cell, tissue, or organism, including the organization of the information in databases.

[7]*Metabolomics* is the systematic study of the unique chemical fingerprints that specific cellular processes leave behind—specifically, the study of their small-molecule metabolite profiles.

- Temperature rise ("heating"),
- voltage-gated ion channels (includes action potential-related channels),
- ion channel electro-denaturation,
- membrane enzyme electro-conformational coupling,
- magnetically sensitive radical pair reactions,
- magnetite-based mechanical coupling, and
- temporary membrane pore creation.

None of these possible mechanisms has so far been positively identified as a candidate for causation of health effect.

Testing for the sensitivity of the central nervous system (CNS) to detect modulated RF signals using the pattern recognition capability of the brain and neural networks would improve our understanding of the minimum signal level that biological systems can sense and distinguish from background noise.

It was noted at the workshop that mechanisms can be modeled theoretically with the use of software-based nonlinear cell models that describe field-induced molecular changes (Weaver 2007; Gowrishankar et al. 2006). It was also noted (D'Inzeo 2007) that investigation of doses occurring on the microscopic level may lead to a better understanding of possible interactions of RF electromagnetic fields on the cellular and subcellular level. The utility of this observation is supported by recent findings (Barnes and Kwan 2005) that suggest a higher energy absorption at the microscopic scale, e.g., at the boundary between cellular structures with different dielectric properties. Several national and international expert groups, including the World Health Organization, have requested more research into micro-dosimetry and appropriate dielectric models as a medium- to long-term research need. Some research programs in Europe already include such investigations.

It is unclear whether low-level RF exposure can trigger effects through stimulation of cellular thermo-receptors. It is also currently unclear if a nonlinear biological mechanism exists that could lead to demodulation effects. As a result, different modulations and wave characteristics would affect biological systems differently. There is some research with respect to this question underway, such as an experiment being conducted in the UK.[8]

Knowledge is lacking concerning the effects of electromagnetic fields on ion and molecular transport through the cell membrane. Work is ongoing at the Massachusetts Institute of Technology, and the outcome should be evaluated before further work is initiated (Weaver and Chizmadzhev 2006).

[8] http://www.mthr.org.uk/research_projects/HO_funded_projects_excell.htm Accessed September 20, 2007.

The committee's evaluation of presentations and discussions at the workshop has resulted in the identification of the following research needs and gaps.

*Research Needs*

**1. Effects of RF electromagnetic fields on neural networks are research needs. There are indications that neural networks are a sensitive biological target.**

**2. Investigations of doses occurring on the microscopic level are needed to better understand possible interactions of RF electromagnetic fields on the cellular and subcellular level. Several national and international expert groups, including the World Health Organization, have requested more research into micro-dosimetry and appropriate dielectric models as a medium- to long-term research need.**

*Research Gaps*

Research Ongoing

1. Mechanisms that can be modeled theoretically with the use of software-based nonlinear cell models that describe field-induced molecular changes. It is currently unclear if a nonlinear biological mechanism exists that could lead to demodulation effects. There is some research with respect to this question underway.

Judged to Be of Lower Priority

2. It is unclear whether low-level RF exposure can trigger effects through stimulation of cellular thermo-receptors.

3. Knowledge is lacking concerning the effects of electromagnetic fields on ion and molecular transport through the cell membrane.

# In Vivo and In Vitro Studies in Experimental Model Systems

Studies performed using in vivo and in vitro (animal and cellular) experimental model systems are critical components of the effort to identify adverse health effects of exposure to radiofrequency (RF) fields generated by wireless communications devices. Experimental studies permit the evaluation of possible risks of RF exposure using well-studied model systems under closely controlled conditions. Well-designed studies in experimental biological models permit the precise quantification of exposure levels, generate essential dose-response data, provide the opportunity to eliminate many external variables that could confound or otherwise alter responses to RF fields, and support comparisons of RF responses to those of chemical and other physical agents using large historical databases in which the effects of those agents have been evaluated in biological models with known ability to predict human responses. Experimental studies can also be designed to include specific endpoint evaluations that can generate important data concerning possible biological mechanisms of RF action. Conversely, however, an unavoidable limitation to data from experimental studies is the requirement to extrapolate data (a) between animal species and (b) from high exposure levels used in the laboratory to lower exposure levels to which humans are commonly exposed. Interspecies differences and high-dose to low-dose extrapolations remain important challenges to the interpretation and application of experimental data to assessments of human risk.

The body of experimental data from studies designed to investigate the possible health effects of exposure to RF fields continues to expand. Well-designed bioassays will include consideration of dose-response relationships.

The state-of-the-science does currently, or will soon, support reasonable conclusions related to the effects of RF exposure on a number of health-related endpoints in laboratory animals (Sienkiewicz 2007; Lai 2007; Roti Roti 2007) and cell-based model systems (Vijayalaxmi 2007). However, data gaps do exist, and a number of possibly critical health effects of RF fields remain to be investigated. In this regard, it should be noted that essentially all experimental studies of RF health effects have been descriptive (e.g., Chou et al. 1992; Vijayalaxmi and Obe 2004) in that they have not been designed to investigate specific hypotheses of disease causation. Indeed, lacking compelling biophysical and biochemical/molecular mechanisms through which RF exposure could play a role in disease causation, investigations of possible links between RF exposure and disease are necessarily empirical. Additional experimental research focused on the identification of potential biophysical, biochemical, and molecular mechanisms of RF action is therefore considered to be an important research need, because it serves as an essential element of a comprehensive hazard assessment.

The following sub-sections are organized into Cancer, Cancer-related Endpoints: Genetic Toxicology, Cancer-related Endpoints: Other, and Noncancer Health Effects.

## CANCER

Perhaps the single most important question concerning the health effects of exposure to RF fields is the possible link between such exposures and cancer risk. Several well-designed, large-scale studies to evaluate the possible oncogenicity of chronic exposure to RF fields in laboratory animals have been conducted (Zook and Simmens 2001; La Regina et al. 2003; Anderson et al. 2004; Tillmann et al. 2007) or are currently in progress. In consideration of the size and strength of the emerging database for studies of the potential carcinogenicity and general toxicity of RF fields, and the quality of the studies that have been and are being conducted, there appears to be only limited value to be gained by initiating additional oncogenicity studies using standard-bred animal models until ongoing studies have been completed. Following completion of these studies, a "weight-of-the-evidence" analysis can be conducted (for example, using criteria established by the International Agency for Research on Cancer) to synthesize and evaluate the entire data set. At that time, rational, informed decisions can be made concerning (a) the value of conducting additional oncogenicity studies in standard-bred laboratory animals and (b) specific design elements that can be incorporated into any such studies in order to address identified data gaps.

Although a large database will soon be available to support evaluations of the possible oncogenicity of RF fields in standard-bred animals, few studies have been conducted in which potential cancer risks have been evaluated using genetically engineered models in which animals demonstrate increased sensitivity to carcinogenesis. The results of such studies could be essential to assessing possible risks of RF exposure in susceptible subpopulations, including individuals with underlying disease, those with genetic alterations that predispose them to oncogenesis, and prior or simultaneous exposure to other carcinogenic or potentially carcinogenic agents. The use of genetically engineered animals may also increase the sensitivity of laboratory studies to detect weak effects, and may be particularly suitable to evaluate the possible interactions between RF fields and other agents in disease causation.

The possible risks of neoplasia (the process of tumor formation) associated with RF exposure in individuals that have been (or are currently) exposed to other environmental or occupational carcinogens may also be investigated experimentally through the use of multi-stage ("initiation-promotion" or co-carcinogenesis) cancer models (Adey et al. 1999, 2000; Zook and Simmens 2001; Bartsch et al. 2002; Anane et al. 2003; Yu et al. 2006). Several such studies have been performed in animal models for cancer in several different organ sites, with uniformly negative results. However, the overall database for RF fields and cancer would be strengthened considerably by additional studies using multi-stage model systems for cancer in tissues (such as the brain) that have been hypothesized to be targets of RF action. Currently the value of such studies is often limited by the lack of suitable animal models that demonstrate the (a) organ specificity and (b) background tumor responses to make them suitable for use in hazard identification.

## CANCER-RELATED ENDPOINTS: GENETIC TOXICOLOGY

As noted at the workshop (Lai 2007, Vijayalaxmi 2007), substantial effort has been put forth to evaluate the possible genetic toxicity of RF fields, both in vivo and in vitro. Although a number of positive outcomes have been reported, efforts to replicate the results of positive studies have generally failed. Furthermore, the majority of experimental studies designed to identify genotoxic effects of exposure to RF fields have not found significant mutagenic or clastogenic activity in any model system that is in broad general use for genetic toxicology evaluations. On this basis, most investigators in the field agree that no compelling body of evidence exists to support the hypothesis that RF fields are genotoxic. The committee concludes that additional studies using standard genetic toxicology test systems are unlikely to increase our understanding of the possible risks associated with RF exposure at this time.

That said, additional genetic toxicology studies may be warranted should evidence of oncogenicity be identified in any of the ongoing chronic toxicity/oncogenicity bioassays of RF fields in laboratory animals, or in any future studies to be performed using genetically engineered animal models. In the event that RF fields are identified as being oncogenic in one or more of these studies, further genetic toxicology studies of RF fields may be warranted as a means to identify possible mechanisms underlying such oncogenicity. Should evidence of oncogenicity be identified in a genetically engineered animal model, additional genetic toxicology studies could be particularly valuable if conducted using cells demonstrating the same molecular defect. Additional genetic toxicology studies could also be of value if performed in cells that demonstrate a predisposition to DNA damage, such as defects in the ataxia-telangiectasia (AT) gene (associated with AT)[1] or deficiencies in DNA repair (e.g., *xeroderma pigmentosum* cells).[2]

## CANCER-RELATED ENDPOINTS: OTHER

Although substantial experimental data are emerging that can be used to evaluate the possible oncogenicity of RF fields, a number of potentially critical cancer-related endpoints have received only very limited study. These include:

- Possible influences of RF exposure on the structure and function of the immune system. Modulation of immune surveillance provides a known mechanism through which exogenous agents may stimulate oncogenesis. The effects of RF on specific arms of host immune function have received very little study in validated immunotoxicology model systems.
- Possible influences of RF exposure on the endocrine system. In consideration of the high incidence of hormone-dependent cancers in the population at large, modulation of hormone synthesis and/or action could also provide an indirect mechanism through which agents may stimulate or inhibit carcinogenesis in hormone-dependent tissues.
- In vitro studies of the effects of RF exposure on cell proliferation, apoptosis,[3] and biochemical and molecular pathways of known significance to carcinogenesis. Although labor-intensive and relatively narrow in scope,

[1] *Ataxia-telangiectasia* is an inherited disorder with symptoms that may include telangiectasis (dilation of capillaries), ataxic (uncoordinated) gait, proneness to infection, defective humoral and cellular immunity, and increased risk of malignancies.

[2] *Xeroderma pigmentosum* is a genetic condition inherited as a recessive autosomal trait that is caused by a defect in mechanisms that repair DNA mutations (as those caused by ultraviolet light) and is characterized by the development of pigment abnormalities and multiple skin cancers in body areas exposed to the sun.

[3] *Apoptosis* is a genetically directed process of cell self-destruction that is activated either by a stimulus or removal of a suppressing agent or stimulus, and is a normal physiological process eliminating unwanted cells.

such studies may identify mechanisms through which RF may induce or stimulate neoplastic development.

- Broadly based (whole genome) investigations of alterations in gene and protein expression in cells exposed to RF fields. Because no reproducible effects of RF exposure on cancer-related endpoints have yet been identified, genome-wide and proteome-wide screening studies can provide an unbiased (although untargeted) approach through which RF-induced changes in biological activities may be identified. Following the initial genome-wide/proteome-wide screening, targeted data analyses and further investigations of pathways that are modulated by RF will be required to identify alterations in gene or protein expression that may underlie neoplastic activity or other toxic effects of RF exposure.

## OTHER HEALTH EFFECTS (NONCANCER)

In addition to cancer-related endpoints, data gaps exist in a number of other areas of toxicology in which knowledge is essential to support a complete evaluation of the possible health effects of RF exposure. These include:

- Possible influences of RF exposure on fetal and neonatal development. Developmental and reproductive toxicity evaluations could include possible teratogenic[4] effects at nonthermal exposure levels, effects on maternal behavior, effects on male and female fertility, and effects on maturation patterns in neonatal and juvenile animals. Although clear evidence of teratogenicity has been demonstrated at RF exposure levels that induce temperature changes, the possible teratogenicity of RF fields at lower (nonthermal) exposure levels has been studied much less extensively. Similarly, the possible effects of RF exposure on neonatal and juvenile growth and development (for example, using endpoints included in perinatal and postnatal development, including maternal function, and toxicology evaluations) have received little study.
- Possible influences of RF exposure on the structure and function of the immune system, including prenatal, neonatal, and juvenile exposures. In addition to possible effects on cancer risk (as discussed above), modulation of immune function could alter host resistance to infectious agents. This could be particularly important in juvenile animals (and children), since their immune system is less developed than in adults.
- Possible influences of RF exposure on the structure and function of the central nervous system, including prenatal, neonatal, and juvenile exposures. Effects on the structure of the nervous system (including the

[4]*Teratogenic* means to be of, relating to, or causing developmental malformations.

blood-brain barrier) could impact a variety of behavioral, emotional, learning, and other higher cognitive functions. It is important to note, however, that changes in central nervous system (CNS) function may also occur without histopathologic evidence of underlying structural damage. Such changes could be assessed through comprehensive neurobehavioral evaluations, such as functional observational batteries that are commonly included in nonclinical toxicology studies; through specialized evaluations of CNS function (e.g., motor activity, acoustic startle, and other more specific neurotoxicology evaluations); and through electrophysiological assessments of CNS function (e.g., electroencephalograms). Neurobehavioral evaluations in juvenile animals exposed to RF may be particularly important, as the juvenile blood-brain barrier is less well developed than in adults; alterations in the blood-brain barrier could have both direct effects on CNS function, and could underlie neurotoxicity by allowing the entry into the brain of substances that are ordinarily excluded.

The data gaps identified above can be addressed, at least initially, through the conduct of descriptive (empirical) toxicology, carcinogenesis, and molecular studies whose goal is general assessment of the impact of exposure to RF fields on toxicological or disease endpoints. Following completion of this set of empirical studies, further progress in the evaluation of the possible health effects of RF exposure will depend on the conduct of hypothesis-driven investigations of putative mechanisms of RF action. At the present time, no generally accepted biological or molecular mechanism has been identified through which RF exposure may impact disease processes. Should exposure to RF fields be found to induce toxicity or increase the risk of any specific disease, the importance of fundamental mechanistic research in our understanding of these effects cannot be overstated, as it will provide the only realistic pathway to a complete assessment of any hazards posed to exposure to RF fields.

The committee's evaluation of presentations and discussions at the workshop has resulted in the identification of the following research needs and gaps.

### *Research Needs*

**1. Additional experimental research focused on the identification of potential biophysical and biochemical/molecular mechanisms of RF action are considered to be of the highest priority.**

*Research Gaps*

### Cancer

Research Ongoing

1. In consideration of the size and strength of the emerging database for studies of the potential carcinogenicity and general toxicity of RF fields, there appears to be only limited value to be gained by initiating additional oncogenicity studies using standard-bred animal models until ongoing studies have been completed. Following completion of these ongoing studies, a "weight-of-the-evidence" analysis can be conducted to synthesize and evaluate the entire data set. At that time, rational, informed decisions can be made concerning:

a. the value of conducting additional oncogenicity studies in standard-bred laboratory animals, and

b. design elements that should be incorporated into any such studies in order to address identified data gaps.

2. The use of genetically engineered animals may increase the sensitivity of laboratory studies to detect weak effects, and may be particularly suitable to evaluate the possible interactions between RF fields and other agents in disease causation.

3. The overall database for RF fields and cancer would be strengthened by additional studies using multi-stage model systems for cancer in tissues (such as the brain) that have been hypothesized to be targets of RF action. At the present time, however, the value of such studies is often limited by the lack of suitable animal models that demonstrate:

a. appropriate organ specificity, and

b. background tumor responses (incidence and latency) to make them suitable for use in hazard identification.

### Cancer-related Endpoints: Genetic Toxicology

4. Although genetic toxicology studies have failed to identify potential RF health effects (in part due to lack of replication of findings from key positive studies), additional genetic toxicology studies may be warranted should evidence of oncogenicity be identified in any of the ongoing chronic toxicity/oncogenicity bioassays of RF fields in laboratory animals, or in any future studies to be performed using genetically engineered animal models.

### *Cancer-related Endpoints: Other*

5. A number of potentially critical cancer-related endpoints have received only very limited study. These include:

a. possible influences of RF exposure on the structure and function of the immune system,

b. possible influences of RF exposure on the endocrine system,

c. in vitro studies of the effects of RF exposure on cell proliferation, apoptosis, and biochemical and molecular pathways of known significance to carcinogenesis, and

d. broadly based (whole genome) investigations of alterations in gene and protein expression in cells exposed to RF fields.

### *Other Health Effects (Noncancer)*

6. In addition to cancer-related endpoints, data gaps exist in a number of other areas of toxicology in which knowledge is essential to support a complete evaluation of the possible health effects of RF exposure. These include:

a. possible influences of RF exposure on fetal and neonatal development,

b. possible influences of RF exposure on the structure and function of the immune system, including prenatal, neonatal, and juvenile exposures, and

c. possible influences of RF exposure on the structure and function of the central nervous system, including prenatal, neonatal, and juvenile exposures.

# References

Adey, W. R., C. V. Byus, C. D. Cain, R. J. Higgins, R. A. Jones, C. J. Kean, N. Kuster, A. MacMurray, R. B. Stagg, and W. Haggren. 1999. Spontaneous and nitrosourea-induced primary tumors of the central nervous system in Fischer 344 rats chronically exposed to 836 MHz modulated microwaves. Radiat. Res. 152:293-302.

Adey, W. R., C. V. Byus, C. D. Cain, R. J. Higgins, R. A. Jones, C. J. Kean, N. Kuster, A. MacMurray, R. B. Stagg, and G. Zimmerman. 2000. Spontaneous and nitrosourea-induced primary tumors of the central nervous system in Fischer 344 rats chronically exposed to frequency-modulated microwave fields. Cancer. Res. 60:1857-1863.

Anane, R., P. E. Dulou, M. Taxile, M. Geffard, F. Crespeau, and B. Veyret. 2003. Effects of GSM-900 microwaves on female rats bearing DMBA-induced tumours. Radiat. Res. 160:492-497.

Anderson, L. E., D. M. Sheen, B. W. Wilson, S. L. Grumbein, J. A. Creim, and L. B. Sasser. 2004. Two-year chronic bioassay study of rats exposed to a 1.6 GHz radiofrequency signal. Radiat. Res. 162:201-210.

ANSI (American National Standards Institute). 1982. American National Standard Safety Levels with respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz. ANSI C95.1-1982.

Armstrong, B., G. Theriaul, P. Guenel, J. Deadman, M. Goldberg, and P. Heroux. 1994. Association between exposure to pulsed electromagnetic fields and cancer in electric utility workers in Quebec, Canada, and France. Am. J. Epidemiol. 140:805-820.

Auvinen, A. 2007. Non-cancer Epidemiology. Presented at the workshop organized by the Committee on Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices, Washington, DC, August 7-9, 2007.

Barker, A. T., P. R. Jackson, H. Parry, L. A. Coulton, G. G. Cook, and S. M. Wood. 2007. The effect of GSM and TETRA mobile handset signals on blood pressure, catechol levels and heart rate variability. Bioelectromagnetics 28(6):433-438.

Barnes, F., and Y. Kwon. 2005. A theoretical study of the effects of rf fields in the vicinity of membranes. Bioelectromagnetics 26(2):118-124.

Bartsch, H., C. Bartsch, E. Seebald, F. Deerberg, K. Dietz, L.Vollrath, and D. Meeke. 2002. Chronic exposure to a GSM-like signal (mobile phone) does not stimulate the development of DMBA-induced mammary tumors in rats: Results of three consecutive studies. Radiat. Res. 157:183-190.

Cardis, E., L. Richardson, I. Deltour, B. Armstrong, M. Feychting, C. Johansen, et al. 2007. The INTERPHONE study: Design, epidemiological methods, and description of the study population. Eur. J. Epidemiol. DOI 10.1007/s10654-007-9152-z.

Chia, S. E., H. P. Chia, and J. S. Tan. 2000. Prevalence of headache among handheld cellular telephone users in Singapore: A community study. Environ. Health Perspect. 108: 1059-1062.

Chou, C. K., A. W. Guy, L. L. Kunz, R. B. Johnson, J. J. Crowley, and J. H. Krupp. 1992. Long-term low-level microwave irradiation of rats. Bioelectromagnetics 13:469-496.

Cook, C. M., D. M. Saucier, A. W. Thomas, and F. S. Prato. 2006. Exposure to ELF magnetic and ELF-modulated radiofrequency fields: The time course of physiological and cognitive effects observed in recent studies (2001-2005). Bioelectromagnetics 27:613-627.

Croft, R. 2007. Human Laboratory Session—Sleep, Cognition. Presented at the workshop organized by the Committee on Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices, Washington, DC, August 7-9, 2007.

D'Inzeo, G. 2007. Mechanisms (Biophysics). Presented at the workshop organized by the Committee on Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices, Washington, DC, August 7-9, 2007.

Gandhi, O. P. 1979. Dosimetry—The absorption properties of man and experimental animals. Bulletin of the New York Academy of Medicine 55:(11)999-1020.

Gandhi, O. P., and M. S. Lam. 2003. An on-site dosimetry system for safety assessment of wireless base stations using spatial harmonic components. IEEE Transactions on Antennas & Propagation 51(4):840-847.

Gowrishankar, T. R., A. T. Esser, Z. Vasilkoski, K. C. Smith, and J. C. Weaver. 2006. Microdosimetry for conventional and supra-electroporation in cells with organelles. Biochemical and Biophysical Research Communications 341:1266-1276.

Groves, F. D., W. F. Page, G. Gridley, L. Lisimaque, P. A. Stewart, R. E. Tarone, et al. 2002. Cancer in Korean War navy technicians: Mortality survey after 40 years. Am. J. Epidemiol. 155:810-818.

Hamblin, D. L., R. J. Croft, A. W. Wood, C. Stough, and J. Spong. 2006. The sensitivity of human event-related potentials and reaction time to mobile phone emitted electromagnetic fields. Bioelectromagnetics 27:265-273.

Hamblin, D. L., and A.W. Wood. 2002. Effects of mobile phone emissions on human brain activity and sleep variables. Int. J. Radiat. Biol. 78(8):659-669.

Hardell, L., M. Carlberg, and K. Mild. 2006. Pooled analysis of two case-control studies on the use of cellular and cordless telephones and the risk for malignant brain tumours diagnosed in 1997-2003. Int. Arch. Occup. Environ. Health 79:630-639.

Hayes, R. B., L. M. Brown, L. M. Pottern, M. Gomez, J. W. Kardaun, R. N. Hoover, K. J. O'Connell, R. E. Sutzman, and N. Javadpour. 1990. Occupation and risk for testicular cancer: A case-control study. Int. J. Epidemiology 19:825-831.

Hietanen, M., A.-M. Hämäläinen, and T. Husman. 2002. Hypersensitivity symptoms associated with exposure to cellular telephones: No causal link. Bioelectromagnetics 23: 264-270.

Hirata, A., S. Kodera, J. Wang, and O. Fujiwara. 2007. Dominant factors influencing whole-body average SAR due to far-field exposure in whole-body resonance frequency and GHz regions. Bioelectromagnetics 28:484-487.

Hocking, B., I. Gordon, H. Grain, and G. Hatfield. 1996. Cancer incidence and mortality and proximity to TV towers. Med. J. Aust. 165:601-605.

Holzapfel, C., J. Vienken., and U. Zimmermann. 1982. Rotation of cells in an alternating electric field: Theory and experimental proof. J. Membr. Biol. 67:13-26.

IEEE (Institute of Electrical and Electronics Engineers). 1996. Microwave Theory & Techniques, Special Issue on Medical Application and Biological Effects of Microwaves Part II.

Keetley, V., A. W. Wood, J. Spong, and C. Stough. 2006. Neuropsychological sequelae of digital mobile phone exposure in humans. Neuropsychologia 44(10):1843-1848.

Kheifets, L., M. Repacholi, R. Saunders, and E. van Deventer. 2005. Sensitivity of children to EMF. Pediatrics 116(2):e303-e313.

Krewski, D. 2007. Cancer Epidemiology. Presented at the workshop organized by the Committee on Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices, Washington, DC, August 7-9, 2007.

Lahkola, A., A. Auvinen, J. Raitanen, M. Schoemaker, H. C. Christensen, M. Feychting, C. Johansen, L. Klaboe, S. Lonn, A. J. Swerdlow, T. Tynes, and T. Salminen. 2007. Mobile phone use and risk of glioma in 5 North European countries. Int. J. Cancer 120:1769-1775.

Lai, H. 2007. In Vivo—Animal and Cell Biology. Presented at the workshop organized by the Committee on Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices, Washington, DC, August 7-9, 2007.

La Regina, M., E. G. Moros, W. F. Pickard, W. L. Straube, J. Baty, and J. L. Roti Roti. 2003. The effect of chronic exposure to 835.62 MHz FDMA or 847.74 MHz CDMA radiofrequency radiation on the incidence of spontaneous tumors in rats. Radiat. Res. 160:143-151.

Leszczynski, D. 2007. In Vitro—Animal and Cell Biology. Presented at the workshop organized by the Committee on Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices, Washington, DC, August 7-9, 2007.

Lonn, S., A. Ahlbom, P. Hall, and M. Feychting. 2004. Mobile phone use and the risk of acoustic neuroma. Epidemiology 15(6):653-659.

McKenzie, D., Y. Yin, and S. Morrell. 1998. Childhood incidence of acute lymphoblastic leukemia and exposure to broadcast radiation in Sydney—a second look. Aust. N. Z. J. Public Health 22:360-367.

Mezei, G., M. Benyi, and A. Muller. 2007. Mobile phone ownership and use among school children in three Hungarian cities. Bioelectromagnetics 28(4):309-315.

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

Parazzini, M., S. Bell, G. Thuroczy, F. Molnar, G. Tognola, M. E. Lutman, and P. Ravazzani. 2005. Influence on the mechanisms of generation of distortion product otoacoustic emissions of mobile phone exposure. Hear. Res. 208:68-78.

Pau, H. W., U. Sievert, S. Eggert, and W. Wild. 2005. Can electromagnetic fields emitted by mobile phones stimulate the vestibular organ? Otolaryngol. Head Neck Surg. 132: 43-49.

Roti Roti, J. 2007. In Vivo—Animal and Cell Biology. Presented at the workshop organized by the Committee on Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices, Washington, DC, August 7-9, 2007.

Rubin, G. J., G. Hahn, B. S. Everitt, A. J. Cleare, and S. Wessely. 2006. Are some people sensitive to mobile phone signals? Within participants double blind randomised provocation study. BMJ 332:886-891.

Russo, R., E. Fox, C. Cinel, A. Boldini, M. A. Defeyter, D. Mirshekar-Syahkal, and A. Mehta. 2006. Does acute exposure to mobile phones affect human attention? Bioelectromagnetics 27(3):215-220.

Sandstrom M., J. Wilen, G. Oftedal, and K. Mild. 2001. Mobile phone use and subjective symptoms. Comparison of symptoms experienced by users of analogue and digital mobile phones. Occup. Med. (Lond) 51:25-35.

Schuz, J., R. Jacobsen, J. Olsen, J. Boice, J. McLaughlin, and C. Johansen. 2006. Cellular telephone use and cancer risk: Update of a nationwide Danish cohort. J. Natl. Cancer Inst. 98:1707-1713.

Schwan, H. P. 1982. Nonthermal cellular effects of electromagnetic fields: AC-field induced ponderomotoric forces. Br. J. Cancer. 45 (Suppl. V):220-224.

Schwan, H. P. 1985. EM-field induced effects. In A. Chiabrera, C. Nicolini, and H. P. Schwan, editors. Interactions between electromagnetic fields and cells. New York: Plenum Press. Pp 371-390.

Sienkiewicz, Z. 2007. In Vitro—Animal and Cell Biology. Presented at the workshop organized by the Committee on Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices, Washington, DC, August 7-9, 2007.

Sievert, U., S. Eggert, and H. W. Pau. 2005. Can mobile phone emissions affect auditory functions of cochlea or brain stem? Otolaryngol. Head Neck Surg. 132:451-455.

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

Tell, R., and E. D. Mantiply. 1980. Population exposure to VHF and UHF broadcast radiation in the U.S. Proceedings of the IEEE 68:6-12.

Tillmann, T., H. Ernst, S. Ebert, N. Kuster, W. Behnke, S. Rittinghausen, and C. Dasenbrock. 2007. Carcinogenicity study of GSM and DCS wireless communication signals in B6C3F1 mice. Bioelectromagnetics 28:173-187.

Tynes, T., M. Hannevik, A. Andersen, A. I. Vistnes, and T. Haldorsen. 1996. Incidence of breast cancer in Norwegian female radio and telegraph operators. Cancer Causes Control 7:197-204.

van Deventer, E. 2007. Research Needs for RF Fields: A WHO Perspective. Presented at the workshop organized by the Committee on Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communication Devices, Washington, DC, August 7-9, 2007 (see also www.who.int/emf for RF Research Agenda).

Vijayalaxmi, and G. Obe. 2004. Controversial cytogenetic observations in mammalian somatic cells exposed to radiofrequency radiation. Radiat. Res. 162:481-496.

Vijayalaxmi. 2007. In Vitro—Animal and Cell Biology. Presented at the workshop organized by the Committee on Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices, Washington, DC, August 7-9, 2007.

Vrijheid, M., I. Deltour, D. Krewski, M. Sanchez, and E. Cardis. 2006. The effects of recall errors and of selection bias in epidemiologic studies of mobile phone use and cancer risk. J. Expo. Sci. Environ. Epidemiol. 16(4):371-384.

Wang, J., O. Fujiwara, S. Koder, and S. Watanabe. 2006. FDTD calculation of whole-body average SAR in adult and child models for frequencies from 30 MHz to 3 GHz. Phys. Med. Biol. 51:4119-4127.

Weaver, J., and Y. Chizmadzhev. 2006. Handbook of Biological Effects of Electromagnetic Fields (3rd Edition), F. Barnes and B. Greenbaum, editors. Biological and Medical Aspects of Electromagnetic Fields. Chapter 9:293-333. New York: CRC Press.

Weaver, J. 2007. In Silico Bioelectromagnetics and In Vivo Biochemical Noise. Presented at the workshop organized by the Committee on Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices, Washington, DC, August 7-9, 2007.

WHO (World Health Organization). 2005. Electromagnetic Hypersensitivity. Fact Sheet No 296, Geneva, Switzerland.

Yu, D., Y. Shen, N. Kuster, Y. Fu, and H. Chiang. 2006. Effects of 900 MHz GSM wireless communication signals on DMBA-induced mammary tumors in rats. Radiat. Res. 165:174-180.

Zook, B. C., and S. J. Simmens. 2001. The effects of 860 MHz radiofrequency radiation on the induction or promotion of brain tumors and other neoplasms in rats. Radiat. Res. 155:572-583.

# Appendix A

# Statement of Task

The National Academies will organize a workshop of national and international experts to discuss research needs and gaps in knowledge of biological effects and adverse health outcomes of exposure to radiofrequency energy from wireless communications devices. Following the workshop, the National Academies will issue a report that draws on the presentations and discussions at the workshop to identify current gaps in knowledge and future research needed to address those gaps. The report will also provide the committee's consensus findings on near-, mid-, and long-term research opportunities.

# Appendix B

# Committee Biographical Sketches

**Frank S. Barnes, Ph.D., NAE,** is distinguished professor in the Department of Electrical and Computer Engineering at the University of Colorado at Boulder. He received a Ph.D. in electrical engineering from Stanford University. His career has included research in a wide variety of applications in physics and electrical engineering, focusing on fundamental research on the biological effects of electromagnetic fields, surgical procedures, and telecommunications education. His research has included the effects of radio waves, fields from power lines, and ultrasonic fields on biological systems—trying to understand the mechanisms of interaction that might lead to identification of hazards, the setting of safety standards, and the establishment of minimum detectable fields. He has been an author of more than 150 papers. Dr. Barnes is an AAAS fellow, an Institute of Electrical and Electronics Engineers (IEEE) fellow, and was elected to the National Academy of Engineering in 2001. He received the Gordon Prize for Innovations in Engineering Education and is a past-president of the Bioelectromagnetics Society (BEMS). Dr. Barnes chaired a National Academies' committee that assessed in four reports potential health effects from exposures to low-level radiofrequency energy produced by a phased-array radar.

**Om P. Gandhi, Ph.D.,** has been a faculty member in the Department of Electrical Engineering at the University of Utah since 1967, where he has been a professor since 1973. He also served as the department chairman from 1992 to 2000. Having worked in the field of bioeletromagnetics (safety assessment and medical applications of electromagnetic fields) since 1973, Dr. Gandhi has expertise regarding electromagnetic (EM) absorption in humans for various public and personnel radio frequency EM exposure environments using anatomically based models of the human body and numerical electromagnetic techniques that are used to understand coupling of EM fields for far- and near-field exposures from power line to microwave frequencies. This expertise includes the use of numerical and experimental techniques for compliance testing of wireless communication devices and development of instrumentation for assessing personnel safety. From 1995 to 2003, Dr. Gandhi served as chairman of the National Council of Radiation Protection's Scientific Committee 89-4 on "Biological Effects and Exposure Recommendations for Pulse-Modulated RF Fields." Dr. Gandhi was elected a fellow of the IEEE in 1979 and received the distinguished research award from the University of Utah for 1979-1980. He received the Utah Governor's Medal for Science and Technology in 2002 and the Microwave Pioneer Award of the IEEE-Microwave Theory and Techniques Society in 2001. He has been president of the Bioelectromagnetics Society (1992-1993), co-chairman of IEEE SCC 28.IV Subcommittee on the RF Safety Standards (1988-1997), and chairman of the IEEE Committee on Man and Radiation (1980-1982). Dr. Gandhi is author or co-author of several book chapters and over 250 peer-reviewed journal articles on electromagnetic dosimetry, microwave tubes, and solid-state devices. When the Specific Absorption Rate (SAR) testing of the cell phone industry was mandated by the FCC in 1993, his laboratory at the University of Utah provided a service to test cell phones during the years 1993-1999 from a number of manufacturers.

**Maila Hietanen, Ph.D.,** is head of the Non-Ionizing Radiation (NIR) Section at the Finnish Institute of Occupational Health (FIOH) in Helsinki, Finland. She has a background in applied physics, and her research interests focus on assessment and prevention of health risks related to human exposure to non-ionizing radiation. In recent years Dr. Hietanen with her research team has been doing research on the neurophysiological and cardiophysiological effects associated with the use of mobile phones. In addition, her research work includes a study on subjective symptoms of persons with perceived electrical hypersensitivity. Dr. Hietanen has been a board member (2001–2007) of the European Bioelectromagnetic Association (EBEA). She has also served on the board of the BEMS, and was an associate editor for the *Bioelectromagnetics Journal* during the years 2003-2005. She has been involved in research cooperation within the European Coordination Action (EMF-NET). She is also the vice-chair of the European COST 281 Action ("Potential Health Implications from Mobile Communication"), and a member of several European and international standards committees (CENELEC, IEC). She was also nominated as the Finnish representative at the International Advisory Committee of the WHO EMF Project.

Dr. Hietanen was invited as a member of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 1996, and elected as the ICNIRP vice-chair for 2004-2008. Currently she is involved in a national research program, which receives funding from the Finnish Technological Agency, which in turn receives some funding from industry in addition to the governmental budget.

**Leeka Kheifets, Ph.D.,** is a professor of epidemiology in UCLA's School of Public Health. Most recently she was head of the Radiation Studies Program at the World Health Organization. Previously she was a technical executive at the Electric Power Research Institute, where she directed a multidisciplinary electric and magnetic fields (EMFs) research program. She taught at the Stanford University School of Medicine in the Department of Health Research and Policy and is widely known for her work in environmental and occupational epidemiology. Dr. Kheifets serves on international and national committees that provide advice to governments on environmental policy. She is a member of the International Committee of the Swedish Radiation Protection Authority (SSI). She has served on committees for the National Research Council, IEEE, and National Council on Radiation Protection and Measurements. Dr. Kheifets was also a member of the National Institute of Environmental Health Sciences, the International Agency for Research on Cancer Working Groups, and WHO EHC Task Groups charged with evaluating potential health effects from EMF exposure. Her research interests include epidemiology of cardiovascular and neurodegenerative diseases and cancer, as well as a methodologic research in risk assessment and policy development. Dr. Kheifets has been a member of the standing committee on epidemiology of the ICNIRP since March 2002. A portion of Dr. Kheifets's funding comes from the nonprofit Electric Power Research Institute (EPRI) to study effects of power-frequency fields (60 Hz). EPRI in turn receives funding from the electrical power industry. She has also consulted for electric utilities.

**Rüdiger Matthes** received his M.E. degree in electronic engineering from the Technical University in Munich. Since 1989 he has served as head of the group "Non-Ionizing Radiation (Dosimetry)" at the German Federal Office for Radiation Protection. The interests of this group cover all aspects of nonionizing radiation protection with the main focus on dosimetry. He has been the scientific secretary of the ICNIRP since 1993. Mr. Matthes is currently coordinating a €17 million German research program on possible health effects from mobile communication technologies. Mr. Matthes himself is a civil servant and thus completely independent from external funding. In addition, the Federal Office for Radiation Protection has a close liaison to the International EMF Project of the World Health Organization.

Mr. Matthes is the German expert in this program that currently reviews scientific evidence in the radio frequency area. ICNIRP is also reviewing the scientific literature in that field. At that organization, Mr. Matthes is chairing the standing committee on physics and technology.

**David L. McCormick, Ph.D., D.A.B.T.,** is senior vice-president and director of IIT Research Institute (IITRI). At IITRI, Dr. McCormick leads the research activities of approximately 150 scientists, technicians, and support staff working in the fields of toxicology, carcinogenesis and cancer prevention, microbiology, molecular biology, and biodefense. He also serves as chairman of Technology Research, Inc., a wholly owned subsidiary of IITRI. Dr. McCormick is the IITRI professor of biology at the Illinois Institute of Technology (IIT), where he teaches undergraduate and graduate courses in physiology and toxicology. He joined the IITRI staff in 1979 and the IIT faculty in 1982. Dr. McCormick received his A.B. degree from Middlebury College (Middlebury, VT) with a joint major in chemistry and biology. He received his M.S. and Ph.D. degrees in environmental medicine/biology from New York University (New York, NY). He is a diplomate of the American Board of Toxicology. Dr. McCormick's primary research activities are in the areas of carcinogenesis and cancer prevention, preclinical and environmental toxicology, and the biological effects of magnetic fields. He has published more than 225 research papers, abstracts, and reviews in these areas. He currently serves as principal investigator on four multiyear research programs supported by the National Cancer Institute, and is principal investigator on the National Institute of Environmental Health Sciences/National Toxicology Program project entitled "Studies to Evaluate the Toxic and Carcinogenic Potential of Cell Phone Radiofrequency Radiation." Dr. McCormick serves on the editorial boards of three scientific journals (*Toxicology, Nutrition and Cancer,* and *The International Journal of Cancer Prevention*) and regularly reviews manuscripts submitted for publication in *Cancer Research; Clinical Cancer Research; Carcinogenesis; Molecular Cancer Therapeutics; Cancer Epidemiology, Biomarkers, and Prevention; Radiation Research;* and *Bioelectromagnetics*; among other journals. He has served on several dozen grant and contract review committees for the National Cancer Institute and other funding agencies. Dr. McCormick is a member of the American Association for Cancer Research, the Society of Toxicology, and the Society for Experimental Biology and Medicine.

**Bernard Veyret, Ph.D.,** belongs to the Centre National de la Recherche Scientifique (CNRS) as "Directeur de Recherche" (senior scientist) at the "Laboratoire de l'Intégration du Matériau au Sytème," within the College of Chemistry and Physics at the University of Bordeaux 1, France. Trained as an engineer in physics and chemistry at the Industrial Physics and Chemistry Higher Educational Institution (ESPCI) in Paris, he joined the CNRS in 1979 and did research on the physical chemistry of the troposphere. Since 1984, Dr. Veyret has turned towards the new field of research on biological effects of electromagnetic fields (bioelectromagnetics). He is now head of the Bioelectromagnetics Laboratory of the École Pratique des Hautes Études. His research team in Bordeaux is composed of about 15 scientists, biologists, and physicists. He was one of the founders of the European Bioelectromagnetics Association (EBEA) in 1989. He belongs to the main commission of ICNIRP and is a member of the International Committee of the Swedish Radiation Protection Authority (SSI). Dr. Veyret has authored more than 75 papers in peer-reviewed journals and co-authored several national and international expert-group reports on EMF and health. He was the chairman of the French expert group on "Extremely Low Frequency Fields and Health" and is a consultant for the French Agency for Environmental and Occupational Health Safety (AFSSET) on the same topic. He is currently a consultant with the World Health Organization (WHO), developing a Web-based EMF course for young scientists working in bioelectromagnetics, and has served as the chairman of the RF research recommendation committee of WHO. He was the coordinator of the European program Perform-B and was an external reviewer for the RAMP 2001 and TeraHertz-Bridge European programs. Dr. Veyret was awarded the 2007 Medal of the French International Union of Radio Science. Dr. Veyret is a member of the scientific council (consulting board) of Bouygues Telecom, which is one of the three French mobile phone providers. His laboratory has contracts with Alcatel and some of the mobile telephone providers to write scientific reports and conduct research.

# Appendix C

# Workshop Agenda

**Committee on Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices**

Workshop
August 7-9, 2007

The National Academies
Keck Center, Room 100
500 Fifth Street, NW
Washington, DC 20001

*Tuesday, August 7, 2007*

**Open Session**
**Room 100**

| | |
|---|---|
| 9:00 am | **Call to order**<br>Description of Meeting, Introduction of Committee Members and Participants<br>Frank Barnes, University of Colorado at Boulder<br>Committee Chair |
| 9:20 | **Perspective on Gaps in Research Needs**<br>Emilie van Deventer, World Health Organization |
| 9:40 | Questions and comments |

**Session 1: Exposure and Dosimetry**

| | |
|---|---|
| 9:50 | **Introduction by Moderator, Rüdiger Matthes**<br>Om Gandhi, Rapporteur |
| 9:55 | **Exposure Systems Presentation**<br>Gernot Schmid, Austrian Research Centers GmbH – ARC, Seibersdorf, Austria |
| 10:15 | Questions and comments |
| 10:20 | **Dosimetry Presentation**<br>Soichi Watanabe, National Institute of Information and Communications Technology, Tokyo, Japan |
| 10:40 | Questions and comments |
| 10:45 | **Comments on Exposure Issues**<br>Ray Neutra, California State Department of Health |
| 11:05 | Questions and comments |
| 11:10 | **Exposure Assessment**<br>Joe Bowman, National Institute for Occupational Safety and Health |
| 11:30 | Questions and comments |
| 11:35 | **Panel Discussion—Session 1 Presenters and Moderator** |
| 12:00 pm | LUNCH in Refectory |

**Session 2: Epidemiology**

| | |
|---|---|
| 1:15 | **Introduction by Moderator, Leeka Kheifets**<br>Naoko Ishibe, Rapporteur |
| 1:20 | **Cancer Epidemiology**<br>Dan Krewski, University of Ottawa, Institute of Population Health, Ottawa, Canada |
| 1:40 | Questions and comments |

1:45 **Noncancer Epidemiology**
Anssi Auvinen, Tampere School of Public Health, Tampere, Finland

2:05 Questions and comments

2:10 **Epidemiology Methods**
Peter Inskip, Division of Cancer Epidemiology and Genetics, National Cancer Institute

2:30 Questions and comments

2:35 **Panel Discussion—Session 2 Presenters and Moderator**

3:05 **Opportunity for Public Comment on Gaps in Research Needs (see sign-up sheet)**

4:00 **Adjourn Open Session for the Day**

*Wednesday, August 8, 2007*

**Open Session**
**Room 100**

8:30 am **Call to order**
Description of Meeting, Introduction of Committee Members and Participants
Frank Barnes, Committee Chair

**Session 3: Human Laboratory Session**

8:45 **Introduction by Moderator, Leeka Kheifets**
Maila Hietanen, Rapporteur

8:50 **Sleep, Cognition**
Rodney Croft, Centre for Neuropsychopharmacology, Swinburne University of Technology, Melbourne, Australia

9:10 Questions and comments

| | |
|---|---|
| 9:15 | **EHS and Well-being**<br>Martin Roosli, University of Bern, Switzerland |
| 9:30 | Questions and comments |
| 9:35 | **Human Peripheral and Central Auditory and Cardiovascular Systems**<br>Paolo Ravazzani, Consiglio Nazionale delle Ricerche, Milan, Italy |
| 9:50 | Questions and comments |
| 9:55 | **Panel Discussion—Session 3 Presenters and Moderator** |

**Session 4: Mechanisms**

| | |
|---|---|
| 10:25 | **Introduction by Moderator, Frank Barnes**<br>Rüdiger Matthes, Rapporteur |
| 10:35 | **Biology**<br>Joe Roti Roti, Biochemistry and Molecular Biophysics, Washington University, St. Louis, MO |
| 10:55 | Questions and comments |
| 11:00 | **Biophysics**<br>Guglielmo D'Inzeo, Department of Electronic Engineering, University "La Sapienza" of Rome, Italy |
| 11:20 | Questions and comments |
| 11:25 | **Need for Models to Improve Our Understanding of Electromagnetic Effects on Biological Systems.**<br>James Weaver (via telephone), Harvard/Massachusetts Institute of Technology Division of Health Sciences and Technology, Cambridge |
| 11:40 | Questions and comments |
| 11:45 | **Panel Discussion—Session 4 Presenters and Moderator** |
| 12:15 pm | LUNCH in Refectory |

**Session 5: Animal and Cell Biology**

| | |
|---|---|
| 1:15 | **Introduction by Moderator, Bernard Veyret**<br>David McCormick, Rapporteur |
| 1:20 | **In Vivo—Animal and Cell Biology**<br>Zenon Sienkiewicz, Health Protection Agency, Radiation Protection Division, Chilton, Didcot, Oxfordshire, UK |
| 1:40 | Questions and comments |
| 1:45 | **In Vivo—Animal and Cell Biology**<br>Henry Lai, Department of Bioengineering, University of Washington, Seattle, WA |
| 1:55 | Questions and comments |
| 2:00 | **In Vivo—Animal Studies**<br>Chiyoji Ohkubo, Department of Environmental Biology, Meiji Pharmaceutical University, Tokyo, Japan |
| 2:10 | Questions and comments |
| 2:15 | **In Vitro—Animal and Cell Biology**<br>Vijayalaxmi, Department of Radiation Oncology, University of Texas Health Science Center, San Antonio, Texas (retired) |
| 2:35 | Questions and comments |
| 2:40 | **In Vitro—Animal and Cell Biology**<br>Dariusz Leszczynski, STUK-Radiation and Nuclear Safety Authority, Helsinki, Finland |
| 2:50 | Questions and comments |
| 2:55 | **Panel Discussion—Session 5 Presenters and Moderator** |
| 3:30 | **Opportunity for Public Comment on Gaps in Research Needs** |
| 4:00 | Adjourn Open Session for the Day |

*Thursday, August 9, 2007*

**Open Session**
**Room 100**

9:00 am **Call to order**
Description of Meeting, Introduction of Committee Members and Participants
Frank Barnes, Committee Chair

**Overarching Issues and Identification of Research Needs**

Introduction of topic: 5 minutes
Open discussion: 15 minutes

9:15 **Effects of Short-term vs. Long-term Exposure**
Frank Barnes, University of Colorado at Boulder

9:35 **Local vs. Whole-Body Exposure**
Om Gandhi, University of Utah, Salt Lake City

9:55 **How Can the Knowledge of Biological Effects from Current Signal Types and Exposure Patterns Be Extrapolated to Emerging Exposure Scenarios?**
Rüdiger Matthes, Federal Office for Radiation Protection, Oberschleißheim, Germany

10:15 **Are There Any Biological Effects That Are Not Caused by an Increase in Tissue Temperature (Nonthermal Effects)?**
Bernard Veyret, Université de Bordeaux, Pessac cedex, France

10:35 **Does RF Exposure Alter (synergize, antagonize, or potentiate) the Biological Effects of Other Chemical or Physical Agents?**
David McCormick, IIT Research Institute, Chicago, Illinois

10:55 **Differences in Risk to Children**
Leeka Kheifets, UCLA School of Public Health, Los Angeles, California

11:15 **Differences in Risk to Other Subpopulations Such as Elderly and Individuals with Underlying Disease States**
Maila Hietanen, FIOH, Helsinki, Finland

11:35 **Opportunity for Public Comment on Gaps in Research Needs**

12:05 pm Adjourn Open Session

# Appendix D

# Workshop Participants

Anssi Auvinen, Tampere School of Public Health, Tampere, Finland
Joe Bowman, National Institute for Occupational Safety and Health, Cincinnati, Ohio, United States
Rodney Croft, Centre for Neuropsychopharmacology, Swinburne University of Technology, Melbourne, Australia
Guglielmo D'Inzeo, Department of Electronic Engineering, University "La Sapienza" of Rome, Italy
Peter Inskip, Division of Cancer Epidemiology and Genetics, National Cancer Institute, Bethesda, Maryland, United States
Dan Krewski, University of Ottawa, Institute of Population Health, Ottawa, Canada
Henry Lai, Department of Bioengineering, University of Washington, Seattle, United States
Dariusz Leszczynski, STUK-Radiation and Nuclear Safety Authority, Helsinki, Finland
Ray Neutra, California State Department of Health
Chiyoji Ohkubo, Department of Environmental Biology, Meiji Pharmaceutical University, Tokyo, Japan
Paolo Ravazzani, Consiglio Nazionale delle Ricerche, Milan, Italy
Martin Roosli, University of Bern, Switzerland
Joe Roti Roti, Washington University, St. Louis, Missouri, United States
Gernot Schmid, Austrian Research Centers, Seibersdorf, Austria
Zenon Sienkiewicz, Health Protection Agency, Radiation Protection Division, UK
Emilie van Deventer, World Health Organization, Geneva, Switzerland

Vijayalaxmi, Department of Radiation Oncology, University of Texas Health Science Center, San Antonio, Texas (retired), United States

Soichi Watanabe, National Institute of Information and Communications Technology, Tokyo, Japan

James Weaver, Harvard/Massachusetts Institute of Technology Division of Health Sciences and Technology, Cambridge, Massachusetts, United States

# Appendix E

# List of Individuals Who Submitted Statements Identifying Needs and Gaps in Research Prior to Workshop

Richard Albanese, M.D., As private citizen
Igor Y. Belyaev, Ph.D., D.Sc., The Arrhenius Laboratories for Natural Sciences
Carl Blackman, Ph.D., U.S. Environmental Protection Agency
Martin Blank, Ph.D., Columbia University
Ben Greenbaum, Ph.D., University of Wisconsin-Parkside
Magda Havas, B.Sc., Ph.D, Trent University
Catherine Kleiber, As private citizen
Dariusz Leszczyski, STUK-Radiation and Nuclear Safety Authority
B. Blake Levitt, As private citizen
James Lin, Ph.D., University of Illinois, Chicago
Michael Milligan, Secretary General, Mobile Manufacturers Forum
Lloyd Morgan, Central Brain Tumor Registry of the United States
Janet Newton, EMR Policy Institute
Cindy Sage, M.A., Sage Associates
Asher Sheppard, Ph.D., Asher Sheppard Consulting
Martin Wolf, Ph.D., Biomedical Optics Research Laboratory