ELECTRIC POWER
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Program on Technology Innovation: Environmental and Health Issues Related to Radiofrequency Emissions from Smart Grid Technologies

Summary of Two Workshops

2011 TECHNICAL REPORT

Program on Technology Innovation: Environmental and Health Issues Related to Radiofrequency Emissions from Smart Technologies

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Product Description

The electrical grid with its associated technologies is experiencing a phase of rapid evolution and expansion. New technological innovations often evoke questions and concerns about health and safety. To address this contingency, EPRI held two workshops in 2011 to (1) identify the electromagnetic environments resulting from emerging technologies, and (2) obtain an understanding of the potential health effects associated with radio-frequency (RF) emissions these technologies produce.

Results and Findings

As a result of the development of the smart grid and associated technologies, the prevalence of many sources of RF fields will increase. These will include wireless communication devices, such as smart meters, and inverters associated with renewable sources, such as photovoltaic cells, and with power electronics, including home appliances, such as washers and refrigerators. Current research regarding the health implications associated with RF emissions of new technologies has focused primarily on the nearly universal use of cell phones. Little information concerning characterization of exposure from projected smart grid and associated technologies is currently available. Though no adverse effects of "non-thermal" exposures have been identified, various unresolved questions remain. These include brain cancer risks from heavy cell phone use, and a consistent observation of slightly altered brain wave activity in human subjects exposed to radio-frequency fields under laboratory conditions.

Challenges and Objectives

Electromagnetic environments are highly complex and a comprehensive accounting of sources and exposures is a challenging objective. Examination of the health literature and understanding the mechanistic basis for observed effects is still at the cutting edge of scientific effort.

Application, Values and Use

This report serves as a reference for the electric utility industry, regulators, technology developers and the public and provides information about the relationship between the electric power industry's smart grid configuration and electromagnetic field exposures. The report also serves to summarize the key uncertainties with respect to potential health effects of radio-frequency fields.

EPRI Perspective

The smart grid and associated technologies offer the promise of greater efficiency and reliability of electricity transmission, distribution and use. As new technologies are developed and introduced into the marketplace, EPRI is well positioned to inform and educate all stakeholders about environmental risks and risk management options associated with technology deployment and operation. This report provides a backdrop for potential future research to address environmental and health issues concerned with smart grid technologies.

Approach

EPRI staff experts met in Knoxville, TN to develop comprehensive information about the technologies and equipment that are likely to populate the transmission and distribution system of the future, as well as residences across the U.S. (and the world). The health workshop in Palo Alto, CA convened an international group of scientists to share their expertise in an effort to review the most important health issues associated with RF exposure and identify priorities for further research.

Keywords

Epidemiology
Exposure assessment
Laboratory animal and human studies
Radio-Frequency (RF) fields
Smart grid
Source characterization

Abstract

The electrical grid and its associated technologies are experiencing a phase of rapid evolution and expansion. New technological innovations often evoke questions and concerns about health and safety. Given this rapid pace of change, EPRI seeks to (1) identify the electromagnetic environments resulting from emerging technologies, and (2) obtain an understanding of the potential health effects associated with radio-frequency (RF) emissions these technologies produce. The first step in this process, funded under EPRI's Technology Innovation Program, consisted of two workshops. The first occurred on June 7, 2011 at EPRI's facility in Knoxville, TN, with the purpose of identifying and describing as comprehensively as possible the sources likely to produce novel electromagnetic environments or increased levels of RF field exposure compared to current levels. The second workshop, which occurred on July 12–13, 2011 at the EPRI offices in Palo Alto, CA, was concerned with the question of whether unresolved health effects issues may arise in connection with RF exposure.

The technology workshop in Knoxville addressed potential exposures from electric vehicles and their charging infrastructure; exposures from inverters associated with equipment such as solar panels, and power electronics (adjustable speed drives) and the pulse wave modulation that will be increasingly used to control appliances and machinery; and radio-frequency exposures associated with wireless communications, with smart meters representing the source that has received the most attention. The Palo Alto workshop focused on RF health studies. The participants reviewed and evaluated the current body of literature which mainly is concerned with exposures from cell phones, likely the greatest source of RF exposure across the population at present. Topics included epidemiology, exposure assessment, animal studies, human laboratory studies, and mechanisms. In addition, the attendees were provided a briefing of the highlights from the Knoxville workshop. At the conclusion, the participants recommended that acquiring more data concerning exposure characterization was a top priority. In addition, the participants acknowledged a consistent effect of RF on brain wave activity that while not considered adverse, was identified as possibly providing insight into a better understanding of RF's mode of action.

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Section 1: Introduction

The electric power industry is on the cusp of major change through the development and evolution of the Smart Grid, in which wireless radiofrequency (RF) technology will play a central role in the transfer of information and data between the customer and the electricity provider, as well as in nearly every interactive data exchange in the power delivery system. Smart meter implementation is still in the early stages, yet will accelerate dramatically over the next decade in the U.S. and other developed nations. Smart meters will usher in a growing array of wireless technology into the home, office and factory as demand-side and supply side technologies are integrated. Adjustable speed drives will likely be integral to most household appliances by 2020. Various stakeholders – the public, industry, scientific community, policy and regulatory bodies - have historically expressed interest in health and safety issues concerned with new technologies and electromagnetic environments in particular. Thus, at this point in time, a fuller understanding of the engineering characteristics of electromagnetic emissions associated with emerging technologies and the issues surrounding potential health effects from such emissions is needed.

Despite the fact that RF has been ubiquitous in our environment since the rapid expansion of AM and FM radio and television in the 20th century, interest in potential health effects associated with RF environments is relatively recent. Health risk concerns have been growing in parallel with the expansion of new wireless technologies, with cellular telephones the most prominent case. The National Cancer Institute estimates that cell phone subscriptions in the U.S. increased from a small handful in 1990, to 110 million in 2000, to 303 million in 2010. Globally, cell phone subscriptions are now estimated at close to 5 billion, nearly one for every person on the planet. Compounding the growth in telephony, expanding application technologies are rapidly turning the cell phone into a multifunction portable computer. Public health concerns have been especially amplified by the widespread and growing use of cell phones by children and adolescents. Exposure starts at a much younger age compared to today's adult population, and will likely continue to grow dramatically throughout their lives as digital technology continues to advance. Exposure patterns are changing so rapidly that they present a moving target for scientists trying to explore potential health risks.

In light of the growing concern among the public regarding RF exposures, particularly with smart meters, EPRI launched an investigation into (1) characterizing electromagnetic field emissions from technologies gaining use within the electricity sector, and (2) identifying research needs in connection with potential health effects associated with these environments. This effort was spearheaded by two workshops:

The Technology Assessment Workshop was held at EPRI's Knoxville office on June 7, 2011. This workshop explored the engineering aspects of the advanced RF-based technology likely to be in use over the next decade, as well as areas for which further RF emission characterization would be advised.

Then on July 12-13, 2011, The International Expert Panel Workshop on RF Health Research was held in EPRI's Palo Alto office. It was attended by experts from various research communities around the world, as well as EPRI staff. The purpose of the workshop was to help EPRI discern priorities in the RF health effects area. The agenda and list of attendees for both workshops are shown in Appendix A.

This report summarizes the proceedings from these two meetings, and is organized as follows:

- Section 1 – Introduction
- Section 2 – Technology Workshop
- Section 3 – Workshop on RF Health Issues
- Section 4 – Bibliography of Health Literature

Introduction to the Workshops

1.1 Technology Assessment Workshop

At the Technology Workshop, EPRI smart grid technology experts teamed with experts familiar with the installation and operation of the technologies. In particular they focused on electrotechnologies of the future, regardless of frequency. The intention was to get ahead of the curve, to strategically roadmap emerging technologies so that in the future, measurement standards and historic databases would be available to those who needed them.

For each technology the participants discussed specific technologies, how they operate, how ubiquitous they are likely to be in 2020 or 2030, potential for RF emissions, information gaps, and future needs. The emerging technologies of greatest interest fell into five broad categories, as follows:

- **Electric vehicles** and charging infrastructure
- **Distributed energy resources**, most particularly rooftop PV and wind turbines
- **Advanced metering infrastructure (AMI)**
- **T&D communications and control** – Every device on the utility system and in the substation is going to be metered and transmitting data.
- **End use power electronics**

Technology Diversity

The difficulty with characterizing, measuring, and monitoring the exposure environment related to RF technology is that it represents a moving target. The diversity of wireless communication technology is growing, as are the interconnections, the clustering and gathering of data at intermediate points, and the variety of applications for which data are needed. Data might be needed for price signals, load flow, customer connection, asset management, power quality, phase balancing, and real time load control, to mention just a few. The upshot is that the greater the information requirements, the greater the duty cycle for devices such as smart meters, and therefore the greater the potential for exposure. The law of bandwith use, according to Parkinson, is that "network traffic expands to fill available bandwidth."

AMI communication involves a wide and growing array of interconnected technologies and service providers, as shown in Figure 1-1. While wireless RF communication is currently the most common mode, powerline and fiber/wired connections are also in use. Each utility tends to have a unique system. Adding to the growing complexity, AMI architectures may be multi-tiered as data move from individual smart meters to access points and concentrators to higher level Meter Data Management (MDM) and other content and customer systems at the enterprise level, as shown in Figure 1-2.

A single meter may be a stand alone, or used to concentrate information from 100 to 1000 other meters, and perhaps more, in order to aggregate and transmit the information efficiently back to the data management system at the utility. Whereas a single meter might be on for a matter of seconds or minutes, concentrators could end up in transmission mode more frequently. Commercially available meters have been found to transmit over a wide range of time depending on the technology and mode of operation.

Right now RF emissions characterization is in its early phase, but the hope is that within a few years EPRI and others will have a protocol and a procedure for each key technology. By 2030, with 60% of the devices in the home utilizing power electronics, understanding their RF emissions will be essential.

Strategic Roadmapping Exercise

The Technology workshop concluded with a strategic roadmapping exercise that first defined objectives and developed ten-year "success statements."

The objectives included:

- Develop a standardized measurement methodology (for each equipment category)
  - Involve manufacturers of relevant equipment, when appropriate
  - Provide credible documentation for each source category
  - Identify (or create) a suite of portable metering technologies suitable for measurements of interest
- Improve the capability of characterizing human exposures

The workshop success statements focused on desirable outcomes in the ten-year time frame. These included:

- 3D mapping capability for all devices of interest
- Understanding the electromagnetic signatures from all devices of interest
- Understanding the relative contribution of smart grid technologies to overall human exposure
- Ability to trend (over time) increase or decrease in RF exposure levels

1.2 RF Health Effects Workshop

The Health Effects Workshop's main purpose was to identify the most important research gaps and to have the collective expertise of the invited participants develop those into specific research priorities. To date, potentially adverse effects from RF have been associated with behavioral disruption linked to a rise in body temperature (of about 1°C) in laboratory experiments. A key specific question was whether and how RF exposures below this threshold might initiate or promote a biological effect that would represent a potential human health risk. These are referred to commonly as "non-thermal" effects.

The Forum

The organizers created an environment for the workshop to facilitate a free, open and creative exchange of views and opinions from the participants, who represented highly diverse backgrounds and experiences. It was felt that dissimilar and/or opposing views would serve to clarify issues, identify gaps in knowledge, and reveal the range of interpretations of the same set of ambiguous data. The ultimate objective of the discussions was to move our understanding of the science forward.

Workshop Organization

The workshop was organized around three main segments. The first segment involved broad overviews of the RF health research by representatives from the National Research Council (NRC), the World Health Organizations (WHO), and the International Agency for Research on Cancer (IARC), an institutional arm of WHO.

The second segment involved presentations and discussion in five topical areas related to potential RF health effects:

- Exposure assessment
- In-vitro laboratory and mechanistic studies
- Animal laboratory studies
- Human laboratory studies
- Epidemiology studies

The third segment was interactive discussion to help frame an array of recommendations for research, to winnow this list down to the top ten, then vote for research priorities through an allocation process.

Process

Each topical area was assigned a presenter and a rapporteur to lead an hour-long discussion among the participants following the presentation. Based upon the discussion, the rapporteur developed three slides for the plenary review process: 1) highlights of the discussion in that particular topical area, 2) the research gaps identified in that area, and 3) a list of research recommendations.

The winnowing process involved a group discussion, a show of hands, and an up or down vote on whether a recommendation warranted inclusion in the top ten. Once the ten were established and clarified, each participant was given a "virtual $100" to allocate among the ten recommendations. Above a minimum level, each participant could allocate any amount to a specific recommendation, thus helping to weight the value of each item. EPRI staff did not vote or allocate priorities.

Workshop objectives included

- Expand the industry's community to include RF health scientists and engineers with expertise in exposure assessment, epidemiology, human and animal laboratory studies, dosimetry and mechanisms;
- Develop a comprehensive understanding of cutting-edge issues related to potential health effects from RF exposure;
- Identify key uncertainties with respect to health effects associated with RF that could be addressed, if needed, through collaborative research.

Success statements include:

- EPRI maintains a readiness to address priority issues concerning RF exposure and potential health effects;
- EPRI effectively reaches out to all stakeholder communities to provide informative and objective materials on RF health issues.

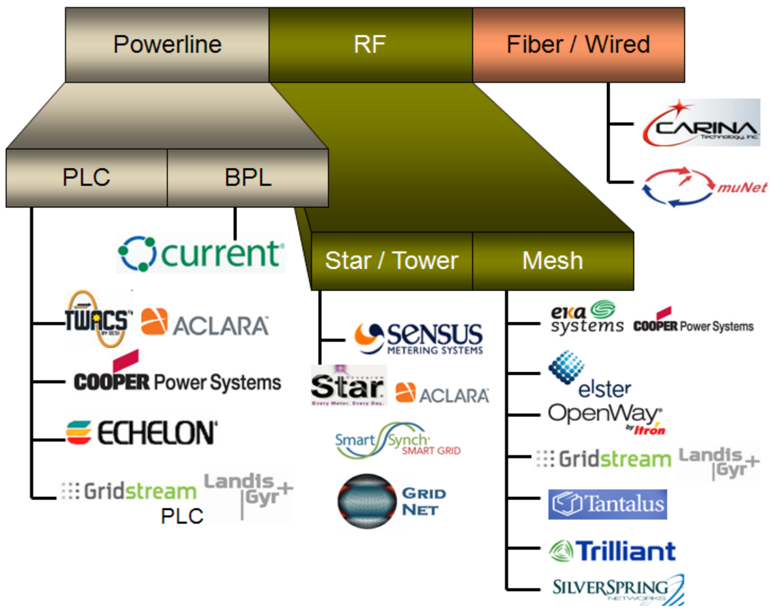


Figure 1-1
AMI Communication Technology Diversity

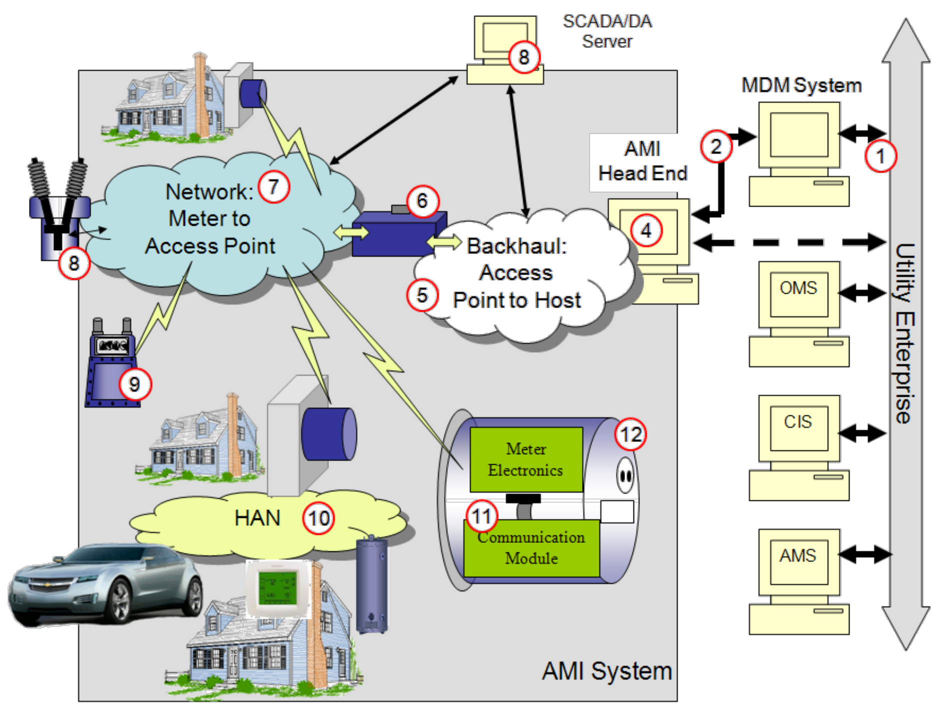


Figure 1-2
Multi-Tiered AMI Architectures

Section 2: Technology Workshop

2.1. Background

Recognizing both the dramatic evolution of the emerging electrical grid technologies (commonly referred to as *smart grid)* and their potential to evoke questions and concerns about health and safety, EPRI has undertaken an initiative to identify and characterize the electromagnetic (EM) environments associated with *smart grid* technologies.

On June 7th, 2011, the Electric Power Research Institute convened a workshop at the EPRI Research Facility in Knoxville, Tennessee to initiate a road-mapping process that would identify power electronics and communication and control technologies deserving of further research attention in the area of human exposure.

The scope of the workshop was limited to technologies that are likely to bear relevance to human health and safety issues that are likely to draw public attention or are relevant for occupational scenarios. The workshop, although mainly motivated by RF exposure issues, also considered other sources in the EM spectrum.

The workshop was focused on the following key objectives:

1. Identify all new and emerging technologies implemented by or on behalf of the electric utility industry with potential EMF emissions
2. Describe the impact of each technology identified in terms of how it is integrated with the transmission or distribution system or locally, such as within a building
3. Describe each technology's current and projected use patterns within the next 15-20 years and identify the potential for EMF exposure
4. Describe how each technology operates, how EMF emissions may occur and what factors may influence typical design features such as required signal processing and properties of signal propagation from antennas. This should also include a description of features such as modulation of wave shapes, spectral content, field magnitude, and spatial and temporal (e.g., duty cycle, time of day use) emission patterns.
5. Characterize each source of EMF emissions and identify the appropriate test protocols for both laboratory and field-based measurements
6. For each technology, identify the existing knowledge gaps, as well as the action plan required to fill them.

2.2. Approach

Prior to the workshop, specific topics on emerging *smart grid* technologies were identified and presentations summarizing their potential future research directions were scheduled. Following the technical presentations and the respective discussion sessions, common issues and priorities for future research related to the technologies covered were identified. The agenda and list of participants are shown in Appendix A.

Over the course of the workshop, seven topics were discussed and relevant action items were noted with respect to particular knowledge gaps. The topics addressed were the following:

- Electric vehicles (EV) and their charging infrastructure
- Distributed generation technologies and their grid interconnections
- End-use power electronics that could be driven by electric utility rebates, incentives or load control requirements
- Utility monitoring communications and control (C&C) technologies
- Advanced metering infrastructure (AMI), including *smart meters*
- Protocols and procedures for replicable EMF measurements

The approximate spectral frequency ranges of EMF emissions associated with the first five of these technology topics are summarized in Figure 2-1.

Each technology-related presentation was geared toward first identifying "what we know" (regarding EMF emissions) and secondly "what we will need to know" to perform conclusive studies on human exposure.

The following sections provide a summary of the workshop presentations and the results of the Q&A sessions.

EMF SOURCE	FREQUENCY RANGE					
	DC	<3kHz	3kHz – 100kHz	100kHz – 1MHz	1MHz – 50MHz	50MHz – 2.4 GHz
Electric Vehicles	√ (Possibly)	√ (Likely)	√ (Likely)		√ (Likely)	√ (Likely)
Distributed Generation	√ (Possibly)	√ (Likely)	√ (Likely)		√ (Likely)	√ (Likely)
Solid State Metering			√ (Possibly)			√ (Likely)
Utility Com & Control			√ (Possibly)		√ (Possibly)	√ (Likely)
Consumer Electronics		√ (Likely)	√ (Likely)		√ (Likely)	√ (Possibly)

√= Likely √= Possibly

Figure 2-1
Frequency Range of Emissions Selected Technology Topics (Red Check = high probability at this time. Yellow Check = possible but less likely)

2.3. Characterization of the EMF Emission Sources

Six EMF emission sources associated with *smart grid* equipment were identified as requiring further characterization in order to support EMF exposure studies:

Communications Hardware – Virtually every component associated with the *smart grid* will require some form of EM communication media (radio, cellular, etc.) for which the full range of emissions and exposure scenarios need to be characterized. The workshop consensus was that the major frequencies related to communications hardware radiated emissions will reside in the 50 MHz (power line carrier) to 2.4 GHz (radio spectrum) window.

Switching Power Electronics Carrier Frequency – The carrier frequency for switching power electronics devices is the frequency of the pulsed waveform, for example an electronic lamp dimmer could have a modulation of pulses at a frequency of 50 kHz. This frequency can be radiated in the vicinity of the lamp itself and conducted on the wires supplying the power. The workshop consensus was that the radiated power electronics carrier frequency emissions will reside in the 2 kHz to 100 kHz window.

Switching Power Electronics Device Rise/Fall Time – Many power electronics devices (from electronic dimmable lighting to inverters and chargers) utilize solid-state high-frequency switching components with pulse waveform characterized by short rise/fall times that can generate EM emissions (shorter rise/fall times will result in higher frequencies). The workshop's consensus was that most of the radiated emissions related to short rise/fall time switching pulses reside in the 5 MHz to 20 MHz window.

Switching Power Electronics Ground Leakage – The previously described carrier and pulse rise/fall emissions generated by switching power electronics may be conducted back onto the power line and can produce additionally radiating fields. To keep these radiated and conducted emissions under regulatory limits, manufacturers add various types of attenuating filters. When these filters are connected to a ground terminal, a leakage current with high-frequency components can be detected on the ground line (e.g. inside a building). This leakage current is generally going to span the entire emission frequency range for the device, from the power line harmonic frequencies (multiples of 50 or 60Hz) up to the frequencies related to switching rise and fall times (MHz range).

Triplen Harmonics – Line-to-neutral connected nonlinear power electronics will generate triplen harmonic currents (the 3rd harmonic at 180 Hz, the 9th harmonic at 540 Hz, the 15th harmonic, etc., for 60Hz power systems). Triplen harmonics do not cancel like other power and harmonic frequencies when recombined on a common neutral for a three-phase (grounded *wye*) electric distribution system and they will produce currents flowing on the neutral conductor. To put the concern about power electronics load proliferation in perspective, the U.S. Energy Information Association (EIA) Annual Energy Outlook 2011 estimated that for commercial and residential buildings the percentage of (nonlinear) power electronics load (not including lighting and HVAC) will increase to near 50% or more by the year 2030.

DC Cabling – Electric transportation and rooftop photovoltaic systems contain cabling that carry DC currents. In general, time-varying current transients in these cables may generate conducted and radiated emissions. For example, some of the newer "net zero" energy installations in California tend to utilize more DC power distribution and there is an emerging market for more energy efficient DC power distribution systems for large computer centers. These DC power distribution systems are still in a technology demonstration phase and the future proliferation of these structures is presently indeterminable.

2.4. Detailed Topical Discussions

The sections below provide a more detailed discussion of the five technology topics listed in Figure 2-1. For each topic, the following questions were addressed:

1. Where should emissions sources be expected?
2. What are the most likely public and worker exposure scenarios?
3. What are the projected future market penetration levels of devices that may increase the emissions?
4. What are the expected spatial ranges of emissions?
5. What temporal patterns of utilization are expected?
6. What EMF emission related measurements have been conducted to date?

2.4.1 Electric Vehicles and Charging Infrastructure

Electric vehicles and their infrastructure constitute one of the largest sources of potential residential load growth for utilities across North America. The electric industry should be positioned to answer questions regarding the emissions from these systems, in particular when the vehicle is being charged at either a residence or in a public parking location.

Emission Sources

Related to electric vehicles, there are a number of emissions sources and design configurations of interest including:

- The inverter/battery charger – either in a residential garage, a public parking area or at a specialized "green site" with renewable power integration
- The vehicle itself with on-board power electronics to convert the DC battery power to a suitable rotational torque and to recapture energy as the vehicles brakes are applied
- The cabling for the AC and the DC power infrastructure (both on-board and off-board)
- Wireless charging if technology becomes technically feasible.

Public and Worker Exposure Scenario

- Residential garage charging and the corresponding emissions during the battery charging cycle – within the garage and nearby residential areas

- Public parking garage where a worker that maintains chargers spends many hours in the vicinity of operating chargers
- Fast charging scenarios related to items 1-2
- The passenger compartment of the vehicle while operating at various speeds
- A vehicle or charger utilizing wireless communications, both for the case of residential and public parking

Projected Market Penetration Levels

It appears likely that the number of electric vehicles will increase over time, but there is a large uncertainty in the projections of the magnitude of this trend. The ultimate share of electric/hybrid vehicles in the motor vehicle fleet will depend on several factors including the price of oil, government policies as well as cost and reliability of the vehicles' battery systems. Nonetheless, the numbers of EV's and hybrid vehicles are trending upward across North America.

Expected Spatial Range of Emissions

There are two main components –on-board emissions and off-board emissions.

On-Board Emissions – The on-board emissions are those that the driver or passengers are exposed to as they operate the vehicle. The expected EMF levels to which people may be exposed can be estimated by considering, for example, average driving distances and commuting patterns. The spectral emission of interest would include: DC, ELF (for which some data already exist), power converter switching (MHz range) and modulation (kHz range) frequencies as well as RF used for wireless communications.

Off-Board Emissions – The off-board emissions are those that the public or workers would be exposed to in the vicinity of the vehicle battery charger. There are no identified test protocols defining appropriate distances from the charger for emission measurements. The emission frequency ranges will be those of the charger switching and modulation for power electronics (MHz and kHz range).

The highest EMF emission levels would be at the highest charger power settings when re-charging a depleted battery. Another scenario potentially associated with the highest EMF emissions would occur during fast charging where the power requirements are five to ten times the typical charge requirements (as much as 20 kilowatts for residential fast charging).

One additional emissions-related issue that needs to be characterized is the charger leakage conducted emissions onto the residential grounding system. Previous testing documented in EPRI meeting reports of the Electric Vehicle Infrastructure Working Council (EV IWC) in the 1990's, indicates that certain charger designs have caused tripping of ground fault circuit interrupters (GFCIs) due to the high frequency leakage emissions. A quantification of these emissions may be more relevant for certain older homes with all-metallic plumbing.

Temporal Patterns

For off-board emissions, the extent of usage will vary by charger type and configuration, but it is generally accepted that the maximum use (for normal charging at a few kW) would be in the order of 4 hours per day and 200 days per year. These numbers may be significantly different in public parking areas and there are currently no data that would describe the full range of usage patterns by location type or application. On-board emissions will be determined by the frequency and duration of the use of the vehicle for transportation.

Measurements to Date

The EV and its charging infrastructure generate a wide spectrum of radiated emissions from DC and power harmonics, to the switching power electronics frequencies and to wireless communications frequencies. To date, very few measurements dedicated to EV related emissions were found to be available and an action item was established to support the development of appropriate measurement protocols for subsequent sets of measurements.

Distributed Generation Technologies

Distributed generation technologies represent a significant growth element for the future electric power grid. In many cases, the local electric service provider will require sufficient communication capabilities to quantify how much power needs to be dispatched at different locations. There is a wide range of power generation technologies, from fuel cells to wind turbines to photovoltaic systems and micro turbines. The workshop consensus was that wind and rooftop solar are the distributed power generation technologies that are most likely to proliferate in the near future and therefore the focus of the discussion was related mainly to those two areas.

The main EMF emissions for distributed generation technologies are due to power conversion equipment (utilizing switched power electronics) that is typically connected directly to the utility grid and is located near the generation plant.

As with electric vehicles and their chargers, the electric industry should be positioned to answer questions regarding the emissions from the power converter and other components of a distributed generation system. Of particular interest would be the scenarios where power electronics are installed in buildings near living areas.

Emission Sources

With respect to *solar panels*, there are a number of emission sources and design configurations of interest including:

- Power conversion unit – typically in the garage or outer wall near the meter base in residential setting.
- Solar panels (in homes with living areas immediately beneath the panels)
- DC power conductors between the solar panels and the inverter

Regarding *wind turbines,* EMF emissions are related to:

- Synchronous power generators associated with the wind turbine
- Power conditioning systems associated with the wind turbine
- Inside the housing of a wind turbine, near the synchronous generator and near the power conversion equipment (for maintenance workers exposure)

Projected Market Penetration Levels

It is expected that the number of wind and solar installations will increase over time, although the exact projection is uncertain due to a number of factors such as the existing dependence on rebates/incentives to offset the cost of new installations. For example, rooftop photovoltaics installations in the State of California have doubled each year since 2008 primarily due to State financial incentive programs.

Despite these uncertainties, the workshop consensus was that there will be sufficient penetration in certain geographical areas to justify the plan of moving forward in the characterization of EMF emissions and of developing a related test protocol for both occupational and residential settings.

Public and Worker Exposure Scenarios

Three exposure scenarios were identified that require characterization of EMF emissions:

- Areas near power conversion equipment for the solar panels
- Areas near solar panels
- Occupational exposure near wind turbine facilities

Expected Spatial Range of Emissions

For solar panels, it was determined that the greatest EMF emissions exposure locations would likely be in residential living areas nearest to the power conversion equipment (radiated) and in a bathtub scenario, where a person in the water contacts a metallic faucet and is in electrical contact (through the water) to a metallic drain simultaneously (conducted emissions).

For wind turbines, the emission scenario of concern would be that of workers who spend a large amount of time in the vicinity of the power conversion equipment or in the area near the synchronous generator.

Temporal Patterns

For solar panels the systems are expected to be active from 2 hours after sunrise to 2 hours before sunset and for the wind turbine scenario the systems are considered active virtually any time workers are inside the housing.

Measurements to Date

The workshop consensus was that there is no sufficient set of measurements to date and an action item was identified to support the development of an appropriate measurement protocol and to perform a set of measurements for both solar panels and for wind turbines.

End-Use Power Electronics

Proliferation of power electronics represents the most significant factor related to devices affecting the *smart grid*, primarily because "smart appliances" are closely linked to demand management and energy efficiency programs. Many devices will be either designed with or controlled by some type of power electronics, *e.g.* variable speed drives for motors, light emitting diode (LED) televisions and most new lighting technologies.

These and other devices have the potential to become part of grid demand response, load control, or energy efficiency future programs and their EMF emissions will need to be quantified. Even though radiated emissions are expected to be at a very low level (relative to FCC limits), presently there are no sufficiently validated data to properly inform the public on this matter.

Emission Sources

Related to end use power electronics, there are three key technologies of interest for EMF emissions:

- Inverters
- Electronic lighting, with particular focus on compact fluorescents that are replacing incandescent lighting
- Appliance power supplies, in particular items part of a demand response incentive program

Public and Worker Exposure Scenarios

Three EMF exposure scenarios were identified:

- Residential living areas with several power electronic devices
- Locations near variable speed drives
- Leakage currents in ground conductors due to power electronics

Projected Market Penetration Levels

As mentioned above, the U.S. Energy Information Administration projected an increase of about 50 percent of power electronics load by the year 2030.

Expected Spatial Range of Emissions

For power electronics, the highest emission levels would likely be in the vicinity of any variable speed drive equipment and could include the bathtub exposure scenario previously mentioned. Future residential loads will have multiple sources of high frequency signals from power electronics and wireless devices: a proper characterization of this scenario that would assess the cumulative emission levels requires a three-dimensional computer modeling capability.

The lack of data on the full spectrum of exposure from various residential EMF sources was identified as a knowledge gap and a thorough characterization of this exposure scenario was identified as a priority.

Temporal Patterns

Typical power electronics devices usage varies and may extend to several hours per day.

Measurements to Date

This area has probably received the most attention in terms of EMF emissions measurements among different devices, but some information is outdated and is certainly not comprehensive. The development of an appropriate measurement protocol for the characterization of various power electronics technologies of interest is required.

Utility Monitoring Communications and Control Technologies

Virtually every component associated with the *smart grid* will require radio, cellular or other communications media for which all the possible EMF exposure scenarios need to be characterized. The workshop consensus was that the major questions related to communications hardware radiated emissions will reside in the 50 MHz (power line carrier) to 2.4 GHz (wireless communication) window.

Utility monitoring communications and control technologies include any utility owned asset with communications capabilities. Examples include transformers, circuit breakers, capacitor banks, and monitoring equipment. This would also include *smart meters*, but AMI is discussed separately in this context.

Two-way communications aspects of utility owned assets will generate EMF emissions; although the likelihood that this could generate concerns for EMF exposure similar to those related to *smart meters* and cell phones is considered small, it was an objective of the workshop to thoroughly address all the technologies associated with the future electric distribution system.

Emission Sources

As present RF communication technologies (both wired and wireless) are used, EMF sources both near the transmitters and on lines utilized for wired communication shall be considered.

Public and worker exposure scenarios

The most relevant occupational exposure scenario is that of utility workers who spend a significant amount of time near the substation. For public exposure the most relevant scenario is that of homes in close proximity to a substation or to other types of installations equipped with RF transmitters.

Projected Market Penetration Levels

The proliferation in the number of telecommunication devices at the grid distribution level is not expected to increase significantly over the next 20 years mainly because the expected growth of distribution lines is limited. However, the majority of the existing hardware will need to be retrofitted with new telecommunication technology. Eventually, every protective and regulation device on today's power grid will be equipped with telecommunication capabilities, although other than at a substation, there are very few scenarios that can be envisioned where there will be multiple telecommunications devices in a single location.

Expected Spatial Range of Emissions

The scenario of most concern will be that of high-density communication nodes (e.g. substations with many communication-enabled devices in close proximity to each other).

Temporal Patterns

For the substation scenario, communication transmissions may be continuous and the emission worst case scenario would be the one determined by the cumulative effect of all of the communications devices operating simultaneously.

Measurements to Date

No known characterizations to this extent have been accomplished to date.

Advanced Metering Infrastructure (Including Smart Meters)

The workshop presentation on the AMI detailed the different *smart meter* designs and programming modes. A variety of options for AMI data transmission has been considered, ranging from power line carrier data transmission to cellular network. Today's advanced meter may include a metrology section, a two-way data communications section, and in some cases a home area network section, and switches to enable or disable power to the home. The AMI technologies use a variety of frequencies, from 220 MHz to 2.4 GHz and have diverse modulations types. They may transmit in either FCC licensed or unlicensed frequency bands.

AMI systems will need to be characterized for all scenarios up the to maximum transmitting power and duty cycle, as the same meter operated in different service territories could exhibit different radiated emissions patterns.

Emission Sources

In regards to the AMI, the workshop consensus was that most of the EMF exposure concerns are related to communications hardware radiated emissions in the 220 MHz to 2.4 GHz frequency range.

Public and Worker Exposure Scenario

The most likely exposure scenario of interest would be that in the vicinity of several *smart meters* installed near a residential area, for example, in apartment complexes. There is also additional interest in the scenario of a single meter near a residence acting as the concentrator for a large number of upstream meters.

Projected Market Penetration Levels

It is projected that by 2020 all U.S. homes will have at least one *smart meter*, while homes with solar panels (metering a net, bi-directional power flow) may have two meters and apartment complexes may have several meters mounted on the same outer wall.

Expected Spatial Range of Emissions

Emissions of interest are in the 220 MHz to 2.4 GHz frequency range.

Temporal Patterns

Transmitter power would be no more than 5 watts, and often far less (~1/4 to 1 W) with the meter transmitting for a cumulative period of just a few minutes each day; whereas there may be scenarios where multiple meters on the side of an apartment complex may transmit for a larger portion of the day.

Measurements to Date

EPRI has performed emissions testing on several *smart meter* brands in cooperation with the electric utilities that are installing those meters. The most complete work to date is documented in the EPRI Technical Reports 1021126 and 1021829.

Repeatable and Replicable Measurement Protocols and Procedures

Regarding the measurement protocols, the workshop consensus was that EPRI is in a unique position to develop the standard methodology for in-situ and laboratory measurements for *smart grid* equipment. This represents an action item for future EPRI work: it is anticipated that the specifications for the equipment and the measurement protocols will have wide reaching impact in terms of standardizing procedures and interpreting measurement data.

On this matter there were two key findings from the workshop discussions:

1. Development and standardization of measurement protocols were identified as a priority
2. There is a need to develop a specification for cost-effective standard measuring equipment that can provide the necessary spectral recordings and dosimetry information needed for the full emission characterization.

2.5. Conclusions

The end of the workshop consisted of a strategic road mapping session to get the experts' perspectives on key goals for the electric utility industry regarding the other-than-60 Hz emissions characterization of *smart grid* equipment.

The following objectives were identified:

1. Define and prioritize the required test equipment
2. Development of a standardized measurement protocol (for each equipment category)
3. Involvement of equipment manufacturers to devise the most effective utilization modes
4. Generation of validated test documentation for each equipment category (both for radiated and conducted emissions, as applicable)
5. Develop standards to quantify EMF human exposure impact
6. Develop a suite of portable metering technologies suitable for field measurements

In addition, a list of success statements was developed:

1. Have the ability to model and simulate the emissions from any *smart grid* device (including a three-dimensional mapping capability)
2. Have standardized test and measurement protocols suitable for all types of *smart grid* equipment characterizations
3. Collect sufficient data from each *smart grid* equipment category to support the characterization efforts

4. Have standard and replicable data available to entities interested in understanding the EMF emissions from any *smart grid* equipment category
5. Have a precise tracking of the annual proliferation of the critical technologies related to EMF emission affecting the electric grid
6. Have a characterization program that will involve utilities, equipment manufacturers, industry organizations and regulatory entities to insure that the level of understanding on the EMF exposure matter is accurate, objective and well disseminated

If the research described in these success statements was accomplished, the electric power industry and the broader stakeholder community would have compiled a significant portion of the information required to inform the public about emissions associated with emerging smart grid technologies.

Section 3: Health Effects Workshop

3.1 EPRI Perspective

Workshop co-chairs, Gabor Mezei and Rob Kavet of EPRI, opened the workshop with perspective on the EPRI RF/EMF research program, as well as an affirmation of the workshop objectives, organization, and processes.

Gabor Mezei, Program Manager for EPRI's electromagnetic field health and safety research oriented the group to EPRI's long range goal of identifying gaps and uncertainties in RF health research related to smart grid technologies and other associated uses of electricity.

Research addressing potential biological and health effects of electromagnetic fields goes back to EPRI's founding in 1973. Mezei explained that the main thrust of EPRI's current health research program on 50-60 Hz fields involves epidemiological and laboratory studies, with the main focus on unraveling the reported association of childhood leukemia with power frequency magnetic fields. Elements of uncertainty still remain with respect to other end points, including miscarriage and neurodegenerative diseases. Extensions of the program to research in other species now include studies on behavior of animals, such as bees, cows, and fish.

The driving force behind extending EPRI's interest in radio frequency is the envisioned transformation of the traditional power delivery system into a comprehensive smart grid over the next 20 years, where control systems will likely utilize wireless communication across a wide spectrum.

The installation of smart meters in homes will increase dramatically in the next few years, as advanced metering infrastructure (AMI) systems are implemented across the US and many other countries.

Indicative of the public concern surrounding smart meter usage, two California assemblymen recently requested that the State investigate whether smart meters are safe and whether current Federal Communications Commission (FCC) exposure limits are protective. The California Council on Science and Technology issued its final report in April, 2011, concluding that, based upon available scientific evidence, the current limits on RF exposure from smart meters are adequate. They recognized that there are gaps in knowledge about potential RF health effects and recommend further research. The International Agency for Research on Cancer (IARC) has classified RF electromagnetic fields as a "possible carcinogen" (Group 2B) based on some studies finding potential associations.

Robert Kavet, senior technical executive at EPRI, provided perspective on four key aspects of assessing potential RF health effects. The first was the fact that all radiofrequency fields deposit thermal energy, not only above but also below the thresholds used to guide standard setting. A seminal experiment by DeLorge first published in 1983, and cited numerous times, has served as a basis for estimating the threshold for thermally-induced behavioral disruption due to RF exposure. This threshold has, in turn, guided the process of setting RF exposure limits by various organizations. The experimental results shown in Figure 3-1 are adapted from a review paper by D'Andrea, Adair and DeLorge published in 2003. It illustrates that while behavioral disruption (upper panel) occurs in a threshold-like pattern, body temperature changes roughly in a linear fashion with RF power density.

His second point was that the brain, which has become the focal point for a great deal of the concern regarding potential risks of RF exposure, is sensitive to a wide variety of external stimuli associated with common experience. Visual stimulation, for example, can not only increase cerebral blood flow, which usually cools the interior of the brain, but can increase the metabolic rate as reflected by oxygen consumption and glucose utilization. Kavet cited a 1998 paper in the *Journal of Sleep Research* by DeBoer to present the notion of the sensitivity of the brain's alpha wave to small changes in brain tissue temperature (the alpha wave was an important topic in the session on human laboratory studies).

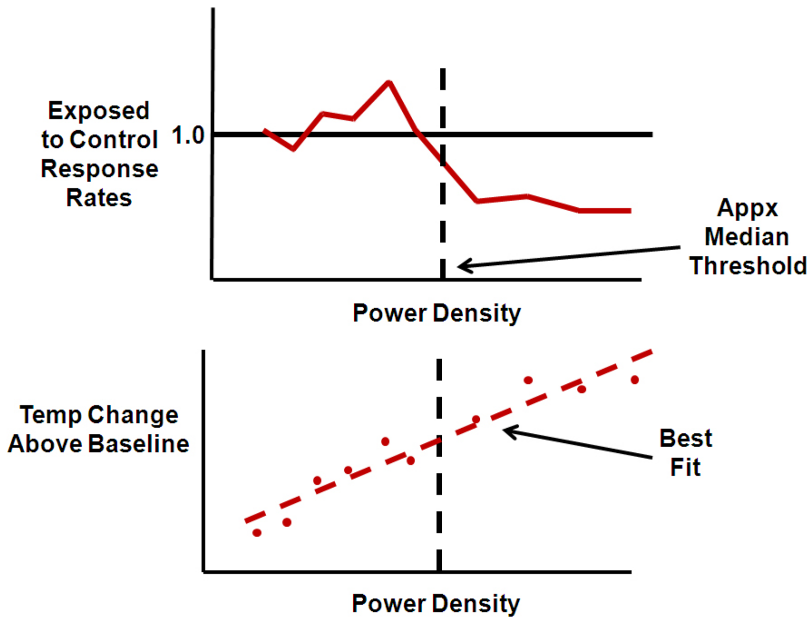


Figure 3-1
Behavioral Effects of Thermal Deposition (adapted from D'Andrea et al., 2003)

His third point was that measurable effects should be viewed in their entirety, as simply different indicators of the larger effects on the entire organism. Sleep patterns, EEG measures, cerebral blood flow, glucose and oxygen utilization, and temperature, among others, should not be divorced from each other, nor studied in isolation.

Kavet's final point was that since adjustable speed drives (ASD) will likely be in all of our appliances within ten years to provide enhanced operational control and efficiency, we should pay particular attention to the RF/EMF fields that result from their modulation patterns. They may emit RF up to 30 MHz, but they also produce significant triple harmonics in the ground system, which consists of the third harmonic of the power frequency (180 Hz) and its odd multiples (9^{th}, 15^{th}, etc.).

3.2 International Research Perspective

Following these opening comments, the chairman invited overviews from key organizations long involved in shaping, guiding, and monitoring the research portfolio on potential RF health effects. Each of them has convened expert panels in recent years to identify research gaps, needs and priorities, and to provide guidance on an integrated approach to the international health effects research effort.

National Research Council (NRC) Perspective

At the request of the FDA, the NRC held a two-day workshop in 2009 to identify research needs and gaps in terms of the biological effects and potentially adverse health outcomes of exposure to RF energy. The Chairman, Frank Barnes, University of Colorado at Boulder, provided an overview of the results of the NRC workshop for the participants of the EPRI workshop. The NRC focus was on near term implementation, and thus did not emphasize basic science needs concerned with biophysical mechanisms and downstream biological events. Some of the key recommendations are now underway in various parts of the world.

At their workshop they defined research needs as areas involving basic understanding of potential adverse health effects, and ranked them with a high priority, while gaps, seen as filling in incomplete areas of knowledge, were given lower priority.

Dosimetry and Exposure

Inadequate exposure data remains one of the major weaknesses of epidemiological studies. When assessing exposure one also needs to consider that absorption of RF energy by the body is a function of frequency, as well as body size, shape and related anatomical features. Young children, for example, have thinner skulls and the relative penetration of RF into the head and resonant frequencies are different from those of a full-grown person. The situation has improved in recent years with a more complete set of exposure models, such as the "Virtual Family" developed by the IT'IS Foundation (Information Technologies in Society) in Switzerland.

The critical research needs identified by the NRC panel in the area of exposure assessment and dosimetry were:

- Better characterization of the exposure of juveniles, children, pregnant women, and fetuses from wireless devices.
- Better characterization of radiation from multiple antennas on base stations, and radiation from antennas located on the sides of buildings.
- More accurate, up-to-date characterization of specific absorption rate (SAR) from current cell phone technology and rapidly changing usage patterns. Overall, the ways in which people are being exposed, and the levels of exposure, are different than those of just 2-3 years ago (e.g., texting). This presents a continuously moving target of exposure, introducing a challenge to health research which by its very nature takes time.

Epidemiology

The greatest need is for epidemiological studies on the most potentially vulnerable populations, notably children and pregnant women. Given the changing nature of RF exposure, the NRC strongly recommended prospective, cohort studies, even though compared to retrospective case-control studies, they take considerably more time and funding to conduct. They also recommended case-control studies of brain cancer associated with children and adolescents who are mobile phone users. In the area of adults, they similarly recommended cohort studies for the evaluation of diverse health end points, including occupational cohorts with medium to high exposures.

Barnes commented on the status of epidemiology since the NRC workshop. He pointed out that 78 papers concerned with RF epidemiology were published in 2010 alone. The most important study released to date, the Interphone study, provided ambiguous results subject to alternative explanations.

A better grasp of the important parameters of exposure will be essential going forward. Which is the most relevant metric? Is it peak power, average power, modulation rates, frequency, or other factors that are the most critical with respect to the assessment of potential health effects?

Mechanisms and In-Vitro Studies

One of the key questions is what is the lowest level at which a biological system can detect the presence of a radiofrequency field. Some animals are remarkably sensitive to radiofrequency fields, but humans may not have evolved with similar sensitivities. The NRC identified several gaps in the area of mechanisms:

- Effects of RF fields on biological neural networks and detection of low levels fields
- Evaluation of RF dose at the cellular level
- Software based nonlinear microdosimetry models of cellular response
- Effects of RF on molecular and ion transport across cell membranes

Barnes has seen some interesting evidence in his lab reporting that 10 MHz fields inhibit cancer cell growth, whereas at higher levels they showed accelerated cancer cell growth. He is also finding some evidence of the ability of RF fields to change free radical lifetimes and concentrations. A question that has not been studied but could prove fruitful is whether long-term repetitive exposures could lead to allergic responses.

World Health Organization (WHO)

One of the core functions of WHO is to shape the international research agenda in critical areas of public health. Their mission is not to perform or fund the research in question, but rather to promote it, while monitoring and assessing global health trends. They set their first EMF research agenda in 1997, and completed their last in 2006, including separate agendas for static fields, ELF and RF. Given the rapid development of RF technology, dramatic increases in cell phone usage, and advances in RF health research, WHO recognized the need to update the RF research agenda. With that objective, they organized a technical consultation meeting in February, 2010, in Geneva, augmented by a broad invitation to 400 experts to submit ideas and background on RF research needs to the consultation group. The result was a recently published report, *The WHO Research Agenda for Radiofrequency Fields*. On behalf of Emilie van Deventer a summary of the report was given to the EPRI workshop by Martin Roosli from the Swiss Tropical and Public Health Institute. http://whqlibdoc.who.int/publications/2010/9789241599948_eng.pdf.

WHO identified four areas of high priority research: epidemiology, human studies, animal studies, and dosimetry. Lower priority research was identified in the areas of cell studies, mechanisms of interaction, and social science research.

Epidemiology

High priority was given to prospective cohort studies of children and adolescents, with endpoints that included behavioral and neurological disorders, as well as cancer. Given the nearly ubiquitous use of cell phones, there was also high-priority support for monitoring brain-tumor incidence trends around the world. Given the dramatic growth in wireless technologies, any significant connection to brain cancer would likely surface in population-wide incidence rates.

Another (lower priority) research need was to conduct case-control studies of neurological diseases, such as Alzheimer's disease or Parkinson disease. Reasonable levels of subject participation, as well as objective exposure data is, however, a prerequisite.

Human Studies

Again with a concern for the developing brain of young children, the WHO consultation team gave high priority to RF/EMF provocation studies on children of different ages to determine when and how the brain responds to RF exposure. They called for related provocation studies to help identify neurobiological mechanisms underlying the effects of RF on brain functions during sleep and resting states.

Animal Studies

The WHO gave high priority to study the potential effects of RF in animal studies specifically prenatal and early-life exposure with respect to developmental and behavioral factors, as well as any possible effects on reproductive organs. The WHO agenda also called for studies of the potential effects of RF on diseases of the elderly, particularly neurodegenerative diseases.

Exposure Assessment

With RF exposures so difficult to measure and such a drawback to traditional health research methodology, the WHO technical team gave high priority to techniques and tools to better characterize RF emissions, to postulate and establish exposure scenarios and corresponding exposure levels. To the extent possible this should be done for new and emerging RF technologies, as well as for changing patterns of use in established technologies, such as texting.

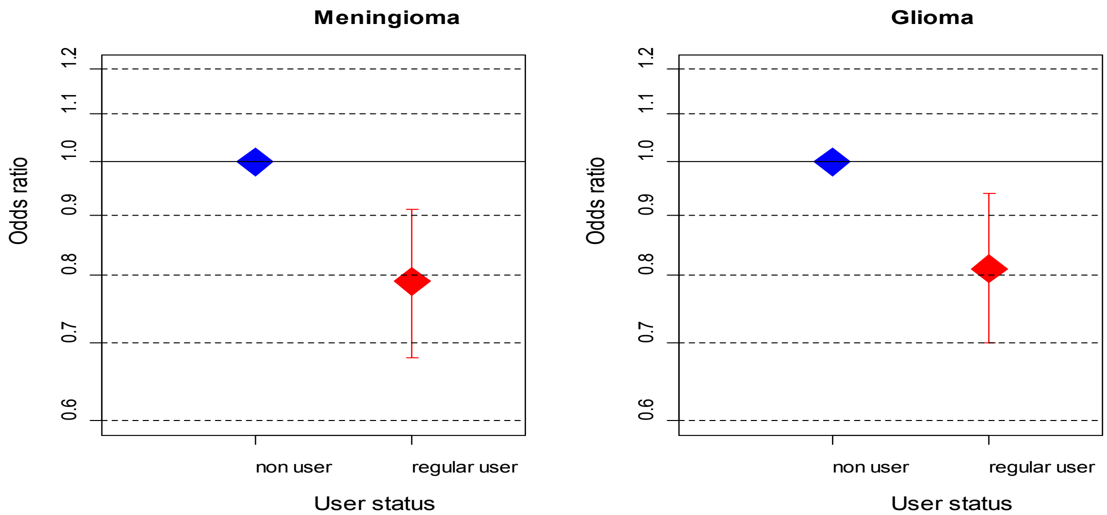
International Agency for Research on Cancer (IARC)

In May, 2011, a committee of 30 scientists from 14 countries met at IARC in Lyon, France, to assess the carcinogenicity of RF. The committee integrated results, findings and interpretations from four sub-committees on epidemiology, animal studies, mechanisms, and exposure/dosimetry, with the first two carrying the most weight. The end result of the meeting was the classification of RF as a "possible carcinogen," Group 2B, which was based on "limited evidence of carcinogenicity in humans" and "limited evidence of carcinogenicity in experimental animals." The term "limited" epidemiologic evidence according to IARC means "a positive association has been observed between exposure to the agent and cancer for which a causal interpretation is considered by the IARC Monographs Working Group to be credible, but chance, bias or confounding could not be ruled out with reasonable confidence." For animal studies, "limited" infers that the weight of evidence has not risen to the level whereby an exposure can be determined to be carcinogenic, but the possibility of a positive response cannot be definitively dismissed. [Note that ELF (or power frequency) magnetic fields were classified 2B on the basis of only "limited evidence of carcinogenicity in humans," with animal data in that case classified as inadequate.]

Epidemiology: Interphone Study

Martin Roosli summarized the epidemiological results of the largest and most influential of epidemiological studies to date, the Interphone study, as well as reviewing incidence trends of brain cancer. The Interphone's results were subject to different interpretations by scientists.

An unexpected result of the Interphone Study was that the odds ratio for regular users of mobile phones, compared to non-users was less than 1.0, roughly 0.8 for both glioma and meningiomas (Figure 3-2). Based upon a validation study by the Interphone team, selection bias might well account for some if not much of this result. Bias could have been introduced through differential patterns of over- or under-reporting actual phone use between cases and controls or differential participation rates. Moreover, when time since start-of-use of mobile phones is examined, the odds ratios are again mainly less than 1.0, reaching approximately unity at the ten-year mark (Figure 3-3). When cumulative call time is the variable in question, there is an increase in the odds ratio above a threshold of around 1600 total hours (Figure 3-4). In particular, the latter finding for cumulative usage has led some researchers to conclude there is enough "limited evidence" to warrant a Group 2B classification. Nevertheless, it is not clear from the Interphone study whether the data are indicative of real risk or recall bias (when subjects do not accurately remember information about their specific level of exposure or associated factors).



Interphone Study
Group, IJE 2010

Figure 3-2
Brain Tumors, Interphone Study, 2010

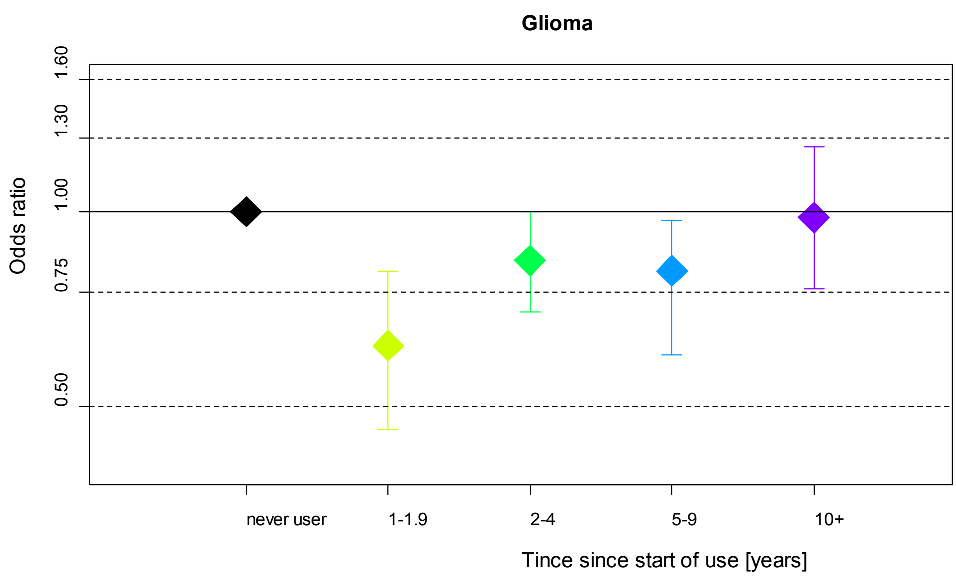


Figure 3-3
Number of Years since Start of Use, Interphone Study, 2010

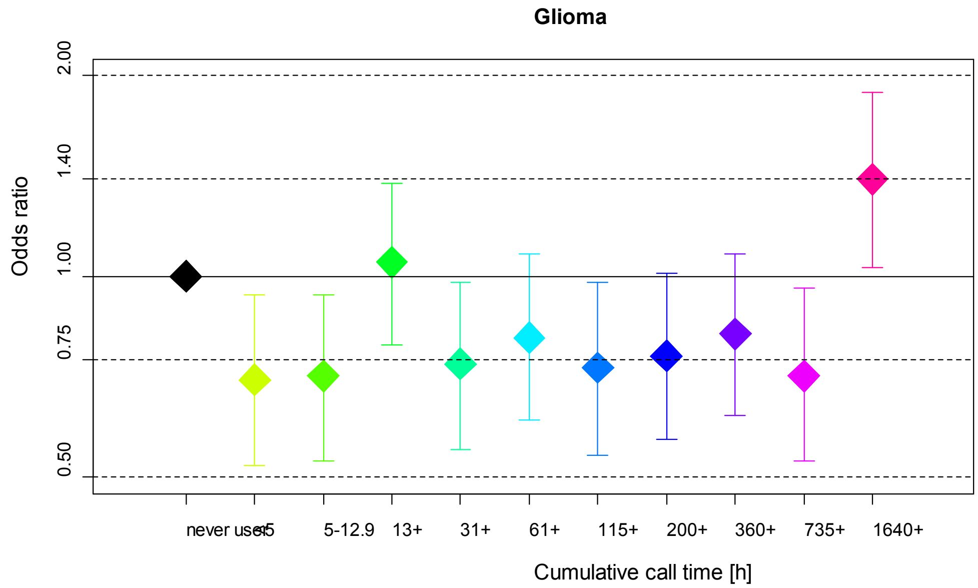


Figure 3-4
Cumulative Call Time, Interphone Study, 2010

Some scientists interpret the Interphone results as indicative of a positive association between RF exposure and cancer. They contend that the signal is weak (i.e., a relative paucity of data for heavy use coupled to variable induction/latency periods) and that the increased risk was most often associated with the "most plausible" exposure groups. Increased risks for use of mobile and cordless phones were also found in several studies conducted in Sweden by Hardell and coworkers. Those interpreting the data as negative point out the inconsistency between the two case-control studies, and the lack of an exposure-response relationship. They add that the Danish cohort study reported no increase in glioma or acoustic neuroma incidence.

Incidence Trends

An argument can be made that if there were a real risk of RF exposure it would be apparent in the temporal trends of brain cancer incidence, especially given the dramatic rise in cell phone use over the last decade. A few studies have been published and most trends have been flat.

However, there are a few subgroups where incidence trends in cancer seem to be increasing. This could be due to chance given the smaller group size. Interestingly, these trends began before the onset of large-scale use of cell phones, so improvements in medical diagnosis could be a factor.

Animal Studies

David McCormick, who chaired IARC's animal subgroup, presented an overall summary of data from animal carcinogenicity bioassays around the world, including from his own laboratory at IIT Research Institute. The reader is referred to the Animal Laboratory Studies, Section 3.4 for greater detail.

To date, 41 oncogenicity studies have been evaluated:

- 34 studies were negative, 7 were positive
- 3 of the positive studies were not confirmed in follow-up studies performed elsewhere
- 4 of the positive studies employed new models or models that have not been used in other laboratories

The conclusion of the IARC subgroup is that "the animal data supporting the possible carcinogenicity of RF is weak, but is non-zero."

3.3 Exposure Assessment

RF EMF exposure arises largely from the burgeoning wireless environment in which we live. The overall exposure environment includes exposure from traditional TV and radio broadcasting; from devices in the home, such as cordless phones and microwave ovens; from commercial, industrial and military communication systems and radar installations; and in recent decades from the dramatic growth in cell phones and mobile computing. In the near future, the smart grid with its reliance on wireless communication for relaying data throughout the entire electric power system and the two-way exchange with the customer via smart meters, will add another layer of RF exposure to the mix. Ric Tell provided an overview of the current state of knowledge in the field of RF exposure assessment. Robert Olsen of Washington State University, the session rapporteur, later led the workshop participants in a discussion.

A study conducted in Switzerland by Frei et al. (2009) reported that, among the general public, 32.0% of cumulative exposure was from mobile phone base stations, 29.1% from mobile phone handsets (with a minor contribution from UMTS relative to GSM), and 22.7% from DECT cordless phones, accounting for over 80% of total exposure with a mean power density of 0.13 mW/m^2 (0.22 V/m).

Exposure assessment is widely regarded as a weak link in health research, especially epidemiology. When exposures were primarily from fixed installations, it was possible to estimate historic population exposure for retrospective, case-control studies. When the exposure environment became primarily mobile in nature, with exposures close to the body predominating, complexity of accurate exposure assessment increased considerably. With rapidly changing technology and usage patterns, exposure assessment is now chasing a moving target. Exposures can shift moment by moment from the head to chest to abdomen depending upon whether the phone is held to the ear, sitting idle in a pocket, or held in front of the body to engage in more visual activities, such as texting, web surfing, or gaming. Moreover, the full constellation of exposures changes as an individual moves through his/her environment in carrying out daily activities.

VHF UHF Broadcast

Exposure from VHF UHF is relatively modest for most of the population, as shown for broadcast fields in Figure 3-5, adapted from Tell and Mantiply (1980). The median exposure to broadcast fields in the U.S., is around 5 nanowatts/cm^2, with less than 1% of the population exposed to more than 1 microwatt/cm^2. These are relatively insignificant levels from the standpoint of energy absorption by the body.

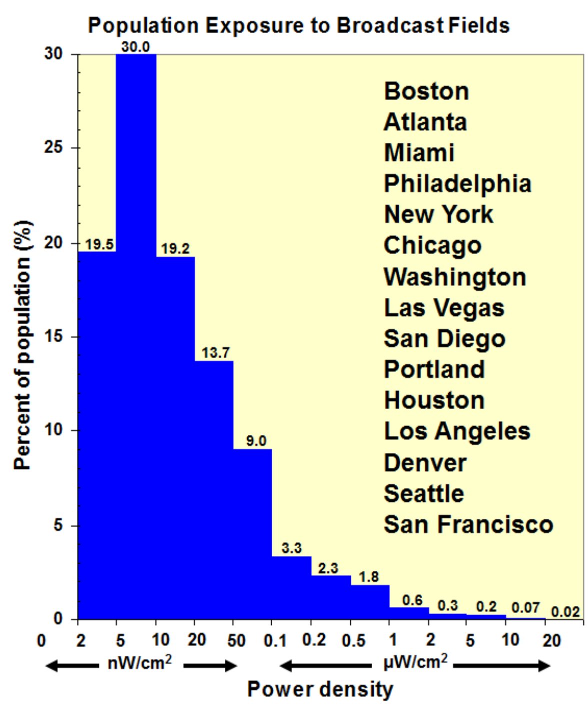


Figure 3-5
Population Exposure to VHF UHF Broadcast Radiation in U.S. (Adapted from: Tell and Mantiply, 1980)

The specific absorption rate (SAR) is defined as the power absorbed per mass of tissue and has units of watts per kilogram (W/kg). SAR is usually averaged over the whole body, or over a local volume of tissue. A recent Belgian study (Joseph et al., 2010) estimated on the basis of measurements accounting for multiple sources that 95% of one-year old children had an average SAR of 7.9 microwatts/kg or less. This compares with IEEE and ICNIRP SAR limits of 0.08 W/kg (80,000 microwatts/kg), and the much higher RF "hazard threshold" SAR which is set to 4 W/kg (4 million microwatts/kg).

In contrast to the general population, high-powered broadcast sites, such as the communication antennae on top of major urban skyscrapers (e.g. the Hancock Center in Chicago) can be the source of significant exposure for individuals working in close proximity. The only clear, immediate RF hazards known to date are from heating caused by overexposure from the fields in very close proximity to the antennas or the RF burns that may be experienced by tower workers and others in similar situations.

Cell Phones

Cell phones are among the largest and fastest growing source of RF exposure to the general public. There are now over 300 million mobile subscriptions in the U.S. (individuals may have more than one), and roughly 5 billion worldwide. RF exposure, however, cannot be captured well by the number of cell phone units or subscriptions. Call volumes are increasing, as are the length of calls, and the device itself has been rapidly morphing over the last decade from a telephone to a smart phone to a mobile computer.

The contrast in RF exposures between mobile phones and stationary broadcasting sources can be seen in Figure 3-6 below. The red line at the bottom represents a relatively high exposure from broadcasting, expressed in terms of an electric field of 1V/m. This is roughly equivalent, in terms of exposure, to a cell phone at a distance of 100 cm (about 3 feet). As the phone is brought closer to the body, up to within an inch of the head, for example, the field rises to 80-100 V/m. Exposure from a phone is also related to the distance between the phone and the base station. The phone must increase its power output to reach a more remote station, therefore, increasing exposure.

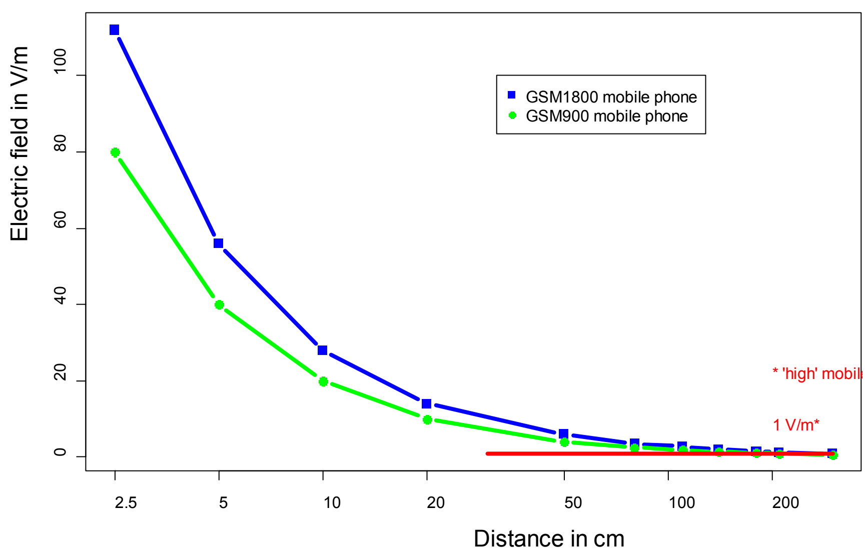


Figure 3-6
Close to Body versus Environmental Sources

Smart Grid

The smart grid (SG) represents the leading edge of a new wave of technology to improve the efficiency, resiliency and usefulness of the electric power system on both sides of the meter. Expansion will build upon and extend some of the core technologies used by electric utilities for supervisory control over the last 15-20 years. They typically use a system of high-power, omni-directional transmitters sending signals at 900 MHz to various switching devices that control the flow of power, coupled with sensors to monitor the flow and communicate the status of the system back to the enterprise. Some of these transmitting towers operate in the range of hundreds of watts. A workshop participant pointed out that the City of Houston, for example, has operated 16 such transmitters for many years, most of which are communicating second by second.

At a finer level, the industry is at an important juncture with regard to the SG. Millions of new installations are due for implementation in the U.S. in the next two years, which means a large expansion of 900-2,4000 MHz devices installed throughout the entire power system to foster two-way communication for enhanced, intelligent control of the transmission and distribution (T&D) system. Further, advanced metering infrastructure (AMI) will help create a seamless integration of the traditional supply and demand functions, bringing information and market dynamics into the home, and the dynamic response of home appliances into the real-time operations of the grid. Everything from appliances to the smart meter to substation will be involved in rapid two-way communication facilitated by wireless RF technology in the 900-2,400 MHz range.

The SG will also serve as a platform for integration of a large array of emerging technologies, ranging from electric vehicles to distributed energy resources to demand response programs and methodologies. Wireless RF technologies will serve as the neural system to coordinate and manage the complexity of the new power system.

The SG and associated technologies will most likely increase the number of RF sources in residential and public locations, from smart meters to advanced appliances to adjustable speed drives, all of which could conceivably increase public concerns over possible health risks. The electricity industry will need to carefully characterize the new exposure environment represented by SG devices in general, and by the smart meter in particular. They will need to be able to place these additional exposures into the broader context of RF exposure in order to respond effectively to public concerns. The rapidly changing scale and nature of cell phone exposure is likely to complicate the health effects debate over smart meters for many years.

Exposure Characterization

The measurement and calculation of dose is one of the most critical aspects of health effects research. Nevertheless, RF dosimetry suffers from significant limitations at present, and personal RF exposure remains one of the weak links in designing and conducting human and animal studies.

Unlike power frequency magnetic fields, RF fields are distorted by the presence of a person, and absorption of RF energy is affected by anatomical factors including height, weight and shape, and the thickness of the skull (thinner in children compared to adults). Furthermore, measuring exposure close to the body from mobile phones is an elusive target with tissue absorption, calculated in terms of SAR, difficult to interpret from field measurements. SAR can vary dramatically depending, for example, upon the position and usage of a cell phone at any given moment.

Time weighted averages of whole body exposure may be at best a crude approximation of dose. Personal dosimeters are usually located in one place on the body, typically the belt. If the brain is the critical organ in RF studies, as most participants agreed, this location on the belt may not capture the most relevant exposures.

Advanced modeling techniques have been developed to translate RF fields external to the body into actual SAR values that can reveal the SAR gradient mapped over the body from different exposures. For example, the SAR pattern from a rod antenna in the near field is shown in Figure 3-7 below. Dosimetry in the future will need to be able to capture the full range and distribution of exposures. What percent of the time is the phone next to the ear, or being used for texting and what are the SAR values? How close is the smart meter to a sleeping person on the other side of the wall and what is the SAR value for the brain? These kinds of questions will frame the next generation of RF exposure studies.

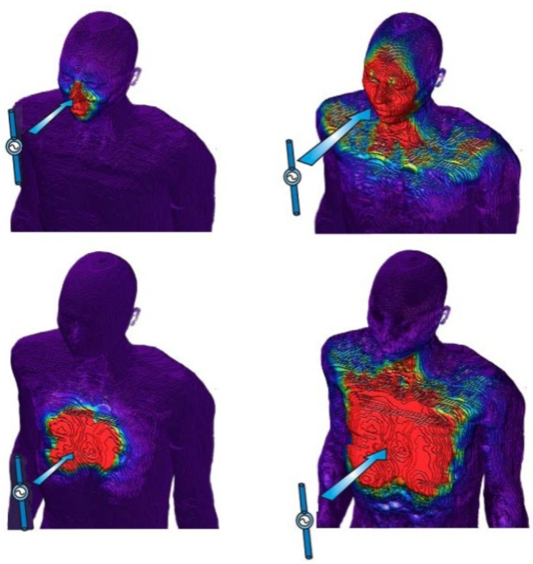


Figure 3-7
SAR Gradients from Rod Antenna (From: EPRI Technical Report 1014048)

In the future, advanced computational dosimetry will be utilized to assess SAR more accurately, to relate the RF field measurements with tissue absorption of energy. The importance of this topic extends to animal studies, as well. This led the WHO to state that expert dosimetry for experimental studies is "critical," and gave it high priority on their research agenda.

Gaps and Research Needs

The workshop participants identified a number of critical gaps and research needs in the broad area of exposure assessment:

- Exposure assessment of RF fields is critical but currently in need of further development. The broad and rapidly changing RF exposure environment represented by mobile phones is not well understood and should be characterized.
- A distribution matrix of cell phone uses would be valuable.
- A similar study is also needed to characterize the RF environment from the multiplicity of devices incorporated into the smart grid.
- The first task in exposure assessment should be a good characterization of "unperturbed" fields. This will provide a baseline for studying the more complex environment of perturbed fields that relate directly to SAR values.
- Dosimetry remains a weak link in epidemiological studies and must be improved to enhance their value.
- Exposure metrics need to be assessed. Time weighted averages may not be the most useful, and other measures, such as peak power, should be evaluated. In particular, a study is needed of the appropriateness of using "time averaged" fields for high amplitude short pulses, such as those encountered near radar installations and on a lower level of intensity, near pulse modulated transmissions, such as Wi-Fi and digital phone signals.
- A study of highly exposed populations (e.g., RF tower workers) would be useful. These populations tend to be small and transitory. It would be useful to identify other, larger, highly-exposed populations for analysis.
- A study of field perturbations close to the body is needed.

Research Priorities

Research priorities for exposure assessment emerged from discussion as follows:

- **Exposure characterization –** Characterize the broad and rapidly changing exposure environment from emerging RF-based technologies, ranging from mobile phones to smart grid metering, controls, and communication technology. As a baseline, exposure characterization should begin with "unperturbed fields."
- **Mobile phone behavior –** Develop an exposure matrix that captures the changing usage patterns and behavior of mobile phone users as it relates to RF exposure, especially among children and adolescents.
- **Exposure metrics –** Evaluate the usefulness, value, and propriety of various exposure metric used in health effects research.
- **High exposure populations –** Assess and measure the exposure environment for subpopulations working in high RF field environments, such as tower workers who maintain broadcast antennas and radar installations.

3.4 Animal Studies

The potential health risks of RF fields can be studied under carefully controlled laboratory conditions using experimental animals and well-established, rigorous methodology. Data from animal and cellular research have long been used as an important complement to human epidemiological studies in identifying and assessing health risks for various exposures.

David McCormick of IIT Research Institute provided an overview of animal research to date on RF exposures, and summarized the current state of knowledge for the workshop participants. He highlighted some key studies now underway or planned, and concluded with an assessment of research needs and research priorities. This was followed by a general discussion led by McCormick and the session rapporteur, Zenon Sienkiewicz from the Health Protection Agency in the UK.

Current State of Knowledge

There is a general consensus that exposure to RF fields at levels that cause thermal effects may pose health risks, particularly in tissues such as the gonads and the eyes. Identifying possible non-thermal effects of exposure to RF is more elusive, and no adverse effects have been identified thus far. For thermal effects, there is a clearly established relationship between absorbed energy (measured as the SAR, specific energy absorption rate), body temperature elevations, and biological effect (including behavioral modification, and in the extreme, mortality), while the possibility of non-thermal effects remain the focal point of considerable animal and human research. Some of the key findings from animal laboratory studies are that:

- **All mortality or gross clinical toxicity** associated with exposure to RF fields appears to be related to their thermal effects. There are no reports in the peer-reviewed literature of increased incidence of premature deaths in rats or mice exposed to RF fields at non-thermal levels.
- **Developmental toxicity** –There is no evidence RF fields are teratogenic when dams are exposed at non-thermal levels. By contrast, there is a clear dose-response relationship linking dam body temperature, fetal death, and teratogenicity in rats.
- **Reproductive toxicity –** Reproductive effects have received limited study to date, but there is no compelling evidence of adverse effects on reproduction from exposure to RF fields at non-thermal levels.
- **Immune function –** No comprehensive studies of RF field effects on immune function have been published. The available evidence does not suggest that exposure to RF fields causes changes in immune function in the absence of heating.
- **Central nervous system (CNS) –** Recent behavioral studies have concentrated on investigating effects of RF fields on memory: no adverse effects have been reported in well performed studies. In terms of the integrity of the blood-brain barrier (BBB), no consistent body of evidence has demonstrated alterations in BBB permeability resulting from exposures to non-thermal levels of RF fields.
- **Summary of thermal versus non-thermal effects**:
  - ***Thermal* –** Animals exposed to high intensity RF fields demonstrated decreased survival,

weight loss, reproductive dysfunction, reduced fetal survival, and BBB changes.

- *Non-Thermal* – No consistent pattern of decreased survival, gross clinical toxicity, developmental or reproductive toxicity, immunotoxicity, CNS toxicity, or changes in BBB permeability have been demonstrated in animals exposed to RF fields at non-thermal levels.

Need for Further Studies

Despite considerable evidence of harmful thermal effects, it is still not possible to assume that there are no adverse effects in animals exposed to RF fields below "thermal levels," generally defined as a rise in core body temperature of about 1°C. The research is simply not complete. As yet, for example, there has been no comprehensive evaluation of possible immunotoxicity or CNS toxicity. Further, and perhaps more importantly, virtually all toxicity studies to date have been performed using adult animals. Considering the extensive and widespread exposure of children to RF signals from cell phones, studies in non-adult animals may be necessary to uncover the potential effects on the developing brain.

The outstanding issue that must be addressed is whether repeated, long-term exposure to RF fields at non-thermal levels is carcinogenic. The "gold standard" approach for carcinogen identification in laboratory animal models is the two-year oncogenicity bioassay. It is accepted by regulatory agencies as the optimal experimental approach. Further, it demonstrates a high degree of concordance with human cancer data, according to the International Agency for Cancer Research (IARC) and the National Toxicology Program (NTP).

To date, seven chronic bioassays have been completed in which animals received long-term exposure to RF fields (Table 3-1); none showed significant increases in cancer incidence in any tissue. However, there have been significant limitations to these studies, notably:

- Limited exposure periods, generally 1-2 hours per day, 5-7 days per week
- Animals have been restrained during exposures, possibly creating stress
- Exposure levels in some studies were selected more for regulatory reasons than scientific reasons
- Adequate but not large group sizes

Table 3-1
Completed Long-Term Animal Carcinogenicity Studies

Author	Species	Strain	Target Organs	Frequency	Outcome
Chou et al., 1992	Rat	S/D	All major organs	Pulsed 2450 MHz	No significant effects
La Regina et al., 2003	Rat	F344	All major organs	FDMA-835.6 MHz CDMA-847.7 Mhz	No significant effects
Anderson et al., 2004	Rat	F344	Brain and other major organs	Iridium-1620 MHz	No significant effects
Smith et al., 2007*	Rat	Wistar	All major organs	GSM-902 MHz DCS-1747 MHz	No significant effects
Tillman et al., 2007*	Mouse	B6C3F1	All major organs	GSM-902 MHz DCS-1747 MHz	No significant effects except decrease in liver adenomas in males at highest SAR

* counted as two studies

Scheduled Studies

A major NTP two-year bioassay is now underway at IIT Research Institute that should help address some of the critical limitations in animal carcinogenesis studies to date. This extensive program will involve:

- Two parallel studies performed on selected strains of mice (B6C3F1) and rats (Sprague-Dawley)
- 90 rodents of each sex in each exposure group
- In both species, parallel groups will be exposed to two different signal modulations (GSM or CDMA IS-95)
- The animals will not be restrained during exposure
- The exposures will be whole body, using reverberation chambers, for 18.5 hours per day for two full years
- The maximum SAR will be selected in consideration of the thermal threshold, defined as 1°C

These in-life phases of the IITRI studies will likely be completed in early to mid 2014 with analysis and results first appearing in the scientific, peer-review literature in 2015.

Data Gaps, Research Needs, and Outstanding Questions

In terms of carcinogenicity, with seven studies completed and the very large NTP study underway, there appears to be little need for additional long-term studies performed using standard approaches in adult animal models. However, there is a critical need for work in several specific areas:

- **Studies in Tumor-Prone Animals** – There is a critical need for studies using an appropriate transgenic or other model for brain cancer. The key challenge is that no suitable models are available.
- **Initiation-Promotion and Co-Carcinogenesis Studies** – There would be a significant need for such studies in the event of either 1) additional positive findings or 2) the development of suitable models for cancer in sites of interest.
- **Metabolic Studies** – There is a need to extend current research to explore the effects of absorbed RF energy on metabolism and food consumption in exposed animals.
- **Behavioral Studies** – There is a need to explore further thresholds for behavioral modification in non-human primates. The benefit would be to provide support for human exposure guidelines.
- **Juvenile Studies** – There is a critical need to study the RF field effects on immature and juvenile animals, including studies on:
  - Behavior and brain function, such as BBB permeability
  - Tumor induction

Outstanding Questions

Some of the outstanding questions in toxicology relate to the effects of RF fields on juvenile animals, specifically:

- Are juvenile animals more susceptible to RF effects than are adults? Should additional studies, for example, immunotoxicology and CNS toxicology, be performed in juvenile animals? Most of the research to date has been performed on adults.
- Are there effects on the development or integrity of the BBB in juvenile animals that are not seen in adults? If so, do these effects underlie CNS toxicity?

Some of the outstanding research questions in carcinogenicity relate to the effects on critical target organs, specifically:

- Do RF fields stimulate oncogenesis in critical target organs (*e.g.*, the brain) in animals with a genetic predisposition to neoplasia in those sites?
- Do RF fields stimulate oncogenesis in critical target organs in animals (*e.g.*, the brain) exposed to low doses of carcinogens having specificity for the target of interest?
- Does *in utero*, neonatal, or juvenile exposure to RF fields increase cancer risk in general?

Research Priorities

Of the numerous possibilities for extending or broadening animal research on the health effects of RF emissions, three stand out. In order of priority, they are:

- **Brain cancer studies in animals predisposed to malignancy**. Studies could be performed in transgenic models, initiation-promotion models, or co-carcinogenic models. The critical challenge is the lack of suitable models.
- **Comprehensive immunotoxicology and CNS toxicology evaluations**.
- **Toxicity and carcinogenicity studies initiated in young animals.**

Strengths and Limitations of High Priority Studies

Studies in tumor-prone animals, as called for in the highest priority research, have both strengths and limitations:

- **Strengths** – Such studies may identify weak effects or effects seen only in susceptible populations; these could be missed in two-year carcinogenicity bioassays.
- **Limitations** – Such studies have some drawbacks: 1) They are generally not accepted by regulatory agencies. 2) There is often limited experience with use of models for hazard identification in concordance with human studies. 3) They are generally targeted at specific organs, which may or may not be relevant to RF field effects in humans.

Studies involving initiation/promotion and co-carcinogenesis similarly have strengths and limitations:

- **Strengths** – These studies may identify weak effects, non-genotoxic effects, or effects of combined exposures, all of which could be missed in two-year oncogenicity bioassays.
- **Limitations** – Such studies have the same drawbacks as tumor-prone studies

3.5 Human Laboratory Studies

Human laboratory studies focus on identifying and measuring real-time physiological effects of RF emissions, as recorded in a laboratory environment under highly controlled conditions. Physiological parameters of interest are largely related to the brain's response to RF, as measured by electroencephalogram (EEG) and positron emission tomography (PET) technologies, and other instrumentation used for testing and measurement. Areas of particular interest are brain responses during waking and sleeping; changes in cerebral blood flow (CBF) and brain glucose metabolism; effects on cognition, in terms of accuracy and response time; and idiopathic intolerance to EMF (electromagnetic hypersensitivity).

Rapidly increasing use of mobile phones, which rely upon the transmission of RF signals close to the head, has led to growing concerns about the potential health risks involving brain function, coupled with growing public demand for more scientific research. The issue is particularly charged emotionally because of the relatively new and dramatic increase in cell phone use by young children and adolescents whose brains are still in a vulnerable state of development. Because cell phone use is such a recent phenomena, the cumulative effects over a protracted period of time are unknown. The possibility remains that there may be biological effects occurring below current exposure limits/guidelines at exposure levels that could be relevant to setting exposure limits. Currently, there are no biophysical mechanisms capable of justifying these health concerns, but further research is called for.

Sarah Loughran from the University of Zurich provided an overview of the current state of knowledge in the field of human laboratory studies, an assessment of the critical gaps in knowledge, and recommendations for research priorities. Loughran and the session rapporteur, Rodney Croft, University of Wollongong, led the workshop participants in a discussion of human laboratory studies.

Current State of Knowledge

Pulse modulated RF EMF signals can induce measurable EEG effects in the brain during both waking and non-REM sleep states. Other studies report some support for altered neural activity from RF emissions, including changes in regional cerebral blood flow (rCBF) and brain glucose metabolism. Whether these physiological effects pose a health risk is still an open question.

Waking and Sleep EEG

EEG analysis is an excellent choice for evaluating and "visualizing" brain activity and brain responses to stimuli. It is a simple, non-invasive technique that primarily reflects synchronous activity in the cortical neurons. It is correlated with vigilance state and cognitive functioning, as well as different stages of sleep.

Typical EEG recordings of brain activity are shown in Figure 3-8, along with the corresponding power spectrum. In the waking state, there is a peak around 8-10 Hz that reflects alpha activity. The second stage of sleep is often characterized by a "sleep spindle," a burst of brain activity around 12-14 Hz. This is an area particularly affected by RF signals. In deep sleep stages, there is a natural shift in brain activity, with lower frequencies between 0.5-4 Hz dominating.

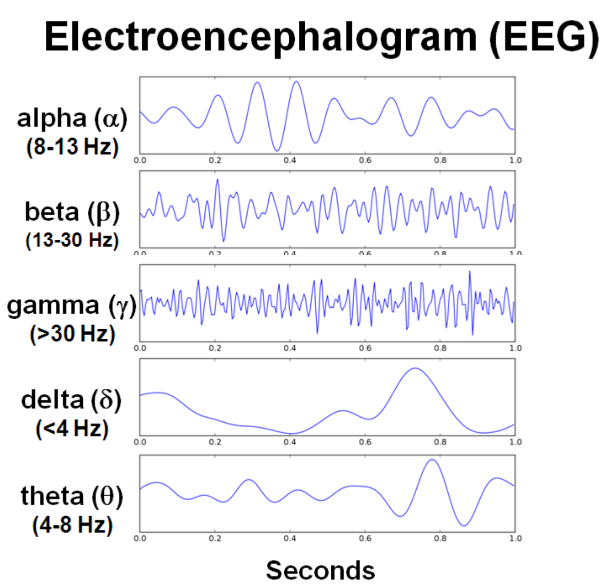


Figure 3-8
A Typical Human Electroencephalogram Displaying the Frequency Classifications as Defined by the Health Council of the Netherlands (2011). (Public Domain)

There is considerable stability in EEG patterns for a given individual over time and under different circumstances, yet considerable variation from individual to individual.

One of the most interesting and consistent findings is that RF fields can induce pronounced changes in the alpha/spindle range of brain activity when the signal is modulated, but not when the carrier signal is continuous (e.g., Huber et al., 2002).

Pulse modulation exposure affects waking EEG in the alpha range and similarly affects non-REM sleep in the spindle range, both around 8-14 Hz. These findings have been replicated in numerous studies, including recent ones with large data sets. Other key findings:

- Effects of RF on the alpha portion of the EEG in the brain have been reported to occur both during the exposure period and well after exposure has ceased in sleeping subjects.
- The specific frequency of the pulsed RF signal seems not to be the overriding factor in induced EEG effects. There is strong indication that it is modulation per se, rather than the frequency of the modulation that is the critical factor in increasing brain activity.
- A few studies have looked at the issue of dose dependency, and found a slight increase in effects when the SAR was increased from 2 watts/kg to 5 watts/kg. Further study is needed to confirm the dose dependency.
- Alterations in neural activity seem unrelated to which side of the head the exposure is positioned.
- Effects are highly variable from individual to individual.

Effects on Regional Cerebral Blood Flow and Brain Glucose Metabolism

Two early studies using PET technology reported that RF fields from an antenna increased regional cerebral blood flow (rCBF) in both hemispheres of the brain. In contrast, a later study, using cell phone exposure rather than an antenna exposure, reported a decrease in rCBF. One study, using positron emission tomography (PET) reported increased glucose metabolism in the brain (BGM) after exposure to RF from a cell phone (Figure 3-9 illustrates a PET scan with the red areas denoting the glucose tracer). In summary, there is some evidence of changes in these two parameters, rCBF and BGM, but limitations in the research to date make interpretation difficult.

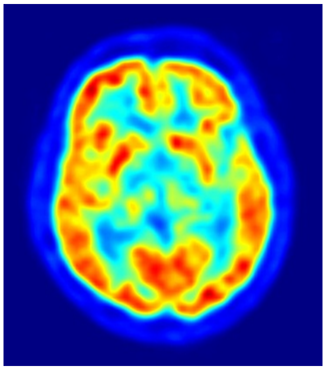


Figure 3-9
A Typical PET Scan with the Glucose Tracer Indicated in Red (Public Domain)

Effects on Cognitive Performance

Numerous studies have been carried out on human cognitive performance over the last ten years, largely in response to concerns over cell phone use. The two endpoints typically investigated are: 1) accuracy of performance, or how well someone carries out a given task, and 2) reaction time, or the speed of performance.

Researchers have primarily investigated two cognitive domains: verbal memory, and working memory.

Results to date remain contradictory, with a handful of studies reporting enhancements in performance, and a handful reporting decrements. However, the majority of studies showed no consistent changes. Recent reviews, along with recent studies using improved methodology, have concluded that mobile phone-like RF exposures do not induce cognitive or psychomotor effects.

Recent studies have looked more specifically at individual variability and geared the tasks being evaluated to individual capabilities. Minor changes in accuracy and response time were found, changes that may be influenced by age.

Idiopathic Environmental Intolerance Attributed to EMF

Idiopathic environmental intolerance to electromagnetic fields is a medically unexplained illness in which symptoms are attributed to exposure to electrical devices. Environmental intolerance as a general syndrome can have major health implications in that it can affect quality of life, increases stress, and can influence occupational and social functioning.

Prevalence of idiopathic environmental intolerance to electromagnetic fields vary widely by country, from a low of 1.5% of the population in Sweden reporting hypersensitivity to EMF to a high of 10% in Germany. California's estimated prevalence is 3.2%.

Repeated experiments have been unable to replicate this phenomenon in the laboratory under controlled conditions. People reporting hypersensitivity, for example, when brought into the controlled laboratory environment have been unable to detect whether the exposure is on or off. There is a suggestion that this is a "nocebo response," in which the individual's suffering is real but the cause of the discomfort is unrelated to the RF exposure.

Major Uncertainties and Research Gaps

While there are consistent physiological effects on brain activity from RF exposure below thermal effect levels associated with behavioral disruption, the underlying mechanisms remain unknown. This is perhaps the single greatest research gap in this area. It is important to understand what is behind these effects now that they have been consistently reported. There is considerable subject-to-subject variability of the EEG response, and further investigation of this aspect may help shed light on the underlying mechanisms of this exposure-induced effect on the EEG.

The relevance to health of EEG brain activity is not clear. There have been no known changes to sleep quality despite all these changes in EEG that we see. It doesn't lead to changes in the time people sleep, or the time it takes them to fall asleep, or to different distributions of the different stages of sleep. Researchers have found consistent effects on the EEG with no obvious downstream correlates.

An important aspect for health research is the potential long-term ramifications. All studies to date have only addressed effects from short-term exposures (acute effects). The significance of long-term, low level exposure to brain physiology is unknown, as are the potential for cumulative and/or adaptation effects.

Is there a potential for effects to get stronger over time analogous to an allergic reaction, or conversely with adaptation, to grow weaker over time? This is a critical area for future research.

Another open issue is whether there are any particular populations that are more sensitive, or more vulnerable? Children or adolescents may be some of the most sensitive groups, because the brain is still developing. Today's children are going to have higher and longer use of mobile phones across their life span than the current cohorts of adults. For this reason, juveniles have been identified as a higher research priority by WHO. Despite this recognition, very little research has been done on this population.

Research Priorities

The two main research priorities are:

- **The neurobiological mechanisms** underlying the effects of RF EMF on the brain.
- **Sensitivity in children and adolescents**.

3.6 Epidemiological Studies

Epidemiology is the scientific discipline concerned with the patterns and determinants of health and disease in human populations. Epidemiology uses design and statistical techniques to quantify relationships between specific exposures and specific health outcomes while adjusting to the extent possible for extraneous factors. Such studies can either be retrospective, usually of case-control design, or prospective, using cohort study design.

Retrospective studies are required to make assumptions about historic exposures, which is highly problematic in the case of RF EMF exposures given the rapid pace of change in cell phone technology and usage patterns, as well as expansion of wireless communication and control technologies throughout homes, business and industry. The shift from second to third generation telecom systems (from Global System for Mobile, or GSM, to Universal Mobile Telecom System, or UMTS) can increase individual exposures from phone usage up to 100 times historic levels.

Cohort epidemiological studies, which take a defined group of people and follow them over time, has the benefit of measuring real-time exposures, but tend to be much more resource intensive.

An overview of epidemiological research on RF exposures was provided to workshop participants by Martin Roosli from the Swiss Tropical and Public Health Institute. Roosli and Raymond Neutra, session rapporteur, then led the follow-up discussion on epidemiology.

Current State of Knowledge

Roosli dichotomized the RF epidemiological studies as (1) "Environmental" for studies dealing with exposures predominantly from background fields, from sources such as telecom base stations, broadcast signals, infrastructure wireless control systems and the like and (2) "Close to Body" the major source of which is cell phones.

Environmental RF EMF

- **Symptom**s – A number of cross-sectional studies have looked at a variety of symptoms, such as sleep disturbance, headache, irritability, dizziness, depression, etc, but found mostly no effects associated with environmental RF exposure.
- **Cognition and behavior** – Very few studies have been conducted on cognition and behavioral effects for RF exposure. One German study found behavioral problems were more common with adolescents, but less so for children, in the highest quartile of exposure.
- **Leukemia** – Nearly a dozen studies have been carried out to characterize the association between leukemia and exposure to local TV and FM radio signals within a few miles. The two largest and most important case-control studies were conducted in Germany and Korea. They both focused on childhood leukemia and its possible association with RF signals from AM radio transmitters located less than 2 km away. The odds ratios in both studies were consistent with unity (0.99 Germany, and 0.93 Korea), indicating no effect from environmental RF EMF.

- **Brain and other cancers** – One notable case-control study in the U.K found no association between exposure from communication base stations and any type of childhood cancer, including brain tumors, leukemia, and non-Hodgkin's lymphoma.

RF EMF Close to the Body

- **Health-related symptoms** – Studies of various health-related symptoms arising from mobile phone usage have presented a mixed picture, a confusing pattern of results underscored by the fact that the mobile phone exposures were self-reported. Self-reporting remains one of the key methodological problems in studies of this type (see Challenges below). One study reported a slightly increased prevalence of migraine and vertigo. Another reported tinnitus risk associated with longer-term usage of mobile phones (> 4years). A study of young adults found frequency of use related to sleep disturbances and depression. A large Swiss study (the only study relying on objective, operator-recorded, mobile phone use data) reported no sleep disturbance among adults.
- **Cognition and behavior** – There is a slight suggestion of cognitive and behavioral issues associated with mobile phone use, warranting further research with more innovative design (see Challenges below). A cross-sectional Australian study of adolescents showed an association with faster and less accurate responses to higher level cognitive tasks. A Danish cohort study of 41,000 children showed behavioral problems associated with both maternal cell phone use during pregnancy and the child's use of mobile phones at age 7.
- **Brain cancer** – Based on numerous studies, there is a suggestion of increased risk of glioma (brain cancer) and acoustic neuroma in long-term mobile phone users with high RF exposure. In the Interphone study, the glioma risk for individuals in the highest quintile of total absorbed energy was 1.35 (with 95% confidence interval of 0.96-1.90); and the odds ratio reached 1.91 for those using cell phones for more than 7 years.
- **Other tumors** – Studies of other tumors are few in number but have shown no noticeable increase in risk.
- **Leukemia** – The one study thus far looking at mobile phone use and adult leukemia reported no increase in risk for regular users. However, similar to other studies, some elevation in risk was suggested for the longest period of mobile phone use.
- **Neurodegenerative disease** – A Danish subscriber cohort study of mobile phone use found no increase in risk for Alzheimer's disease, ALS, Parkinson's, multiple sclerosis, or epilepsy.

Major Challenges and Knowledge Gaps

Exposure Measurement Challenges

Accurately estimating exposures for individual study subjects remains a very challenging exercise. Any health study's validity relies on the validity of its exposure assessment. The following issues were identified:

- **Participation and selection bias.** The consistently observed deficit in risk of brain tumors among cell phone users in most case-control epidemiologic studies may be an indication of participation or selection bias. Refusal to participate in these studies was reported to be associated with use of cell phones, which, in combination with lower participation rates among controls than cases, may be an explanation of downward bias in risk estimates.
- **Where and how to measure exposure.** Do measurement devices worn on the belt provide reasonable approximation of exposure? Are phone records meaningful? With growing differences among networks, and phone applications, it is increasingly problematic whether usage corresponds to dose. Which is the most meaningful measure of exposure: time weighted average exposure, peak exposure, cumulative exposure? How would one account for the changing nature of phone usage, as for example, texting, where the device is held not to the ear, but in front?
- **Self reporting bias.** Numerous epidemiological studies rely upon self reported exposure. Yet careful studies have shown that self-reporting is inaccurate. With retrospective studies, in particular, self-reporting is prone to recall bias. People with symptoms tend to overestimate their exposure.

- **Retrospective exposure difficulties –** Historic exposures are often very different than current or prospective exposures, weakening the value of retrospective, case-control study methodology. Prospective studies may be the best solution in a rapidly changing environment of wireless technology.
- **Multiple source complexity –** Individuals are increasingly exposed to RF fields from multiple sources: phones, broadcast, communication devices in the home, business, and office, etc. With the onset of the smart grid, many appliances in the home will be using wireless communication to exchange data. How to combine those fields for exposure assessment is a large and growing challenge.
- **Reverse causality –** Mobile phone use is a lifestyle-related exposure. The individual using a smart phone for three hours a day lives a highly specialized lifestyle. Like the "healthy worker effect," the healthy individual may communicate more, creating a situation of reverse causality. This makes cross-sectional studies very unreliable.

Long Term Assessment

A number of RF health studies dealing with different end points have reported slight elevations in risk over time, suggesting that studying today's adults may not be a reliable indicator of the effects on the next generation. Children will be subject to far greater exposures during their lifetimes than adults, and will be subject to these exposures during their most vulnerable stages of development.

The mix of exposure sources is evolving in so many different ways, which could handicap the predictive value of today's epidemiological studies.

Innovative Design

Communication is an integral part of being human, and communication technology is rapidly evolving to increase the accessibility, style, frequency, immediacy, method, and emotional content of communication choices. Thus, behavior, cognition, and communication become an integrated whole, defying unidirectional causality.

To uncover adverse health effects from the physical RF emissions will require innovative design in behavioral studies that complement traditional epidemiological approaches.

Research Priorities

- **Monitor brain tumor incidence trends –** Given the rapid expansion in RF technology and dramatically increasing cell phone use, careful monitoring of brain tumor incidence around the world is called for. If there were a risk, it would almost certainly become clear over time. Conversely, if the incidence of brain cancer does not increase, after factoring in improved diagnostic procedures, it would be a good indicator that mobile phone use does not play a major role in brain cancer. Given the difficulties with exposure assessment, monitoring incidence trends may be a convenient way of ascertaining whether overall trends might be attributable to increasing use of sources, such as cell phones.
- **Innovative designs for measuring behavioral changes in children and adolescents –**There are suggestions of behavioral changes being induced by RF EMF exposure but current research design is handicapped in numerous ways, including reverse causality, where behavior changes phone use, rather than the other way around. Innovative research design, including prospective cohorts, could help ameliorate some of these problems.
- **Objective exposure data –** Self-reporting techniques add further complications to exposure measurements. New instrumentation and/or methodologies are needed to overcome the limitations imposed by subjective reporting of exposure by individuals likely to overestimate or underestimate the duration and nature of usage.
- **Neurodegenerative disease –** This is an area that has been significantly under researched, and could conceivably become an important area for future investigation (as indicated in the WHO research agenda).

3.7 Mechanisms

RF health effects research has not yet identified an underlying biophysical mechanism that could lead to adverse health effects in humans either at the biomolecular level or the systemic level. In general, photonic, electric, and magnetic field interactions with charged components of a biological system can produce effects based on thermal mechanisms where the absorbed energy is dispersed to all modes of the biomolecular system. Alternatively, non-thermal mechanisms have been proposed for circumstances where there did not appear to be a significant temperature increase. Non-thermal mechanisms involve energy absorption in selected modes of various kinds, that is, resonant absorption. Direct thermal effects, which can be found at high field intensities such as those from broadcast antenna, are reasonably well understood, but non-thermal effects are not. Johnathan Kiel and Asher Sheppard led the workshop discussion on mechanistic studies of RF fields where researchers have conducted analyses using physical, biophysical and chemical theory, and conducted experiments in-vitro, often on cells in tissue culture, and on laboratory animals. Discussions were informed by the observation that there is a hierarchical ordering of effects that must begin with a physical interaction potentially followed by biochemical effects, physiological effects, and finally a possible effect on the behavior or health of the organism. The importance of conducting experiments and analyses that lead to quantifiable outcomes, in contrast to heuristic approaches and methods where outcomes are not quantified, was emphasized repeatedly during workshop discussions on mechanisms.

Current State of Knowledge

Although RF energy can affect bulk matter, inspection of the many possible mechanisms shows that by a very large factor the energy in RF fields from typical wireless sources cannot be sufficiently concentrated to change chemical structure or binding (i.e., affect chemical reaction rates). In terms of photon energy, RF energy available to chemical bonds is much too weak for a direct effect on existing heat-driven Arrhenius reactions. Sufficient energy would require at least a frequency in the infrared range. The quantum of energy needed for such changes also cannot be obtained by any of the amplification mechanisms that have been proposed in the past, including focusing, dielectric discontinuity, multi-photon absorption, and long-term accumulation in low-energy modes. In light of the ubiquity of water molecules in living matter, the strong damping of molecular motions by water is a fundamental obstacle to most mechanisms for energy transfer from RF fields to biological molecules. Moreover, nearly all proposed mechanisms create electrical, chemical, temperature, and physiological changes ("signals") that are so much weaker than noise levels inherent in biological matter that they cannot have any discernible effect.

Cellular and analytic studies have established the characteristics of biologically significant thermal mechanisms, including:

- Physiological functions in cells that can be affected by relatively small temperature changes on the order of 1K.
- Specialized thermo-sensitive cells and thermo-sensitive organs that can respond to temperature differences of <0.1K, and in some cases of the order of 0.01 K.
- Thermal diffusion makes it impossible to achieve temperature differences of more than 10^{-6} K (one micro-kelvin) between points separated by cellular or sub-cellular dimensions. Consequently, an intracellular, organelle, or membrane temperature differential is not a plausible mechanism for microwave biological effects.

It is highly desirable that RF health studies, including epidemiological studies, be designed with an understanding of possible mechanisms of interaction that could cause health effects. However, attempting this approach using established mechanisms that might affect cells electrophysiologically indicates a need for field strengths in the body so extremely intense that they cannot be obtained from environmental exposures to wireless RF sources (with possible exceptions of some extreme occupational situations). Electrophysiological mechanisms generally involve movement of ions through cell membrane ion channels, a process that occurs very slowly with respect to RF oscillations. Therefore, any field-driven ion translational movement during one-half cycle of the oscillating RF field is rapidly reversed in the following half-cycle.

Direct interactions of electromagnetic radiation with genetic material, including cellular DNA, have been investigated experimentally, with conflicting reports for effects at moderately strong levels. Quantitative analyses showed there is no plausible mechanistic model for effects on genetic material, and the various biological and biochemical processes in which genetic material is involved. Thus, examination of potential theoretical mechanisms has provided no guidance to experimentalists in search of low-level RF biological effects.

In addition to the foregoing considerations based on energetics, it also is useful to consider constraints indicated by the time constants that characterize chemical reactions. In context of RF fields that oscillate at rates of approximately 10^9 Hz or more (corresponding to 1 GHz and higher), some relevant second-order reaction rate constants are those for enzyme turnover (10^6–10^8 s^{-1} M^{-1}), diffusion-controlled reactions (typically, 10^9–10^{10} s^{-1} M^{-1}, and up to 10^{11} s^{-1} M^{-1} for small molecules), proton transfer reactions (10^{10}–10^{11} s^{-1} M^{-1}), and free radical reactions (10^{10}–10^{11} s^{-1} M^{-1}). Ion-dependent signaling and transport at cell membranes behave like enzyme reactions with time constants in the range 10^6–10^8 s^{-1} M^{-1} . Thus, chemical reactions generally occur over times that are long compared to the period of an RF field and any effects would have to be in response to the average field, but not dynamically or resonantly to time-variations of the RF field.

As a result, with the possible exception of interconversion of free-radical spin states, researchers to date have found no physical theory to support the existence of low-level, non-thermal effects between approximately 10 MHz and hundreds of gigahertz (Sheppard et al., 2008). Specific limitations for some proposed mechanisms alluded to above include:

- Small quantum energy of microwave photons
- Absence of molecular resonances below ~150 GHz
- Applied fields in body tissues very much weaker than natural fields and noise fields inherent in matter
- Frequency cutoffs for translational motion of ions far below the microwave range
- Signal-to-noise (S/N) ratios smaller than one by orders of magnitude
- Thermal diffusion too rapid for occurrence of "micro-thermal effects" – that is, temperature gradients at cellular dimensions insignificantly small
- Structural or optical focusing of energy on the anatomical level insufficient to cause low-level effects, with the possibility of field enhancements on the nanostructural level

Comprehensive Mechanisms List

Most of the numerous possible mechanisms fall into three basic categories: mechanisms involving RF heating, mechanisms that enhance RF energy absorption, and by far the largest category, proposed dynamical effects on charged particles, which includes biochemical mechanisms (Sheppard et al., 2008).

RF Heating Raises Temperature

- Heat balance and physiological stress
- Biochemical reaction rates
- Microthermal (spatial, temporal contexts)

Enhanced RF Absorption

- Structure enhances E-field
- Non-uniform dielectric properties

Dynamics of Charged Particles

- Ion transport rate through protein channel
- Radical-pair mediated chemical kinetics
- Reaction rates synchronized with pulsing of RF energy
- Electroconformational change in proteins
- Electrostimulation of excitable tissues
- Magnetic dipole interaction (H·m): magnetite (including effects on gating charges)
- Ion transport by dielectrophoretic forces (for $\nabla \cdot \boldsymbol{E}$ non-zero)
- Molecular conformation:
  - Directly, by "athermal" absorption of RF energy
  - Indirectly, by chemical change, or thermal activation (e.g., Na-K ATPase, polymerases, cyclohexane)
- Multi-photon absorption
- Molecular motors
- Transfer of neurotransmitters, hormones, exocytosis
- Noise-driven ("stochastic resonance")
- Non-equilibrium dynamical effects
- Molecular resonance

- Signal rectification; demodulation
- Endogenous fluxes significant for excitation-contraction, signaling, development, wound healing
- Counterion polarization
- Anomalous diffusion of energy via normal modes
- Vibrational wave packets in cytochrome-c, MGb, GrnFluoProtein
- Cumulative charge displacement by RF field-modified charge distribution at membrane
- Rapid (< 10^{-7} s), localized (< 10^{-6} m) energy absorption
- Direct field effect on molecular structure (affecting chemical functions)
- Strong field effects without weak field analogies
- Transient membrane pore formation
- Induced apoptosis
- Transmembrane ion flux, trans-membrane potential
- Non-resonant effects on chemical kinetics (via changes in molecular structure)
- Many-body interactions; non-linear dynamics
- Magnetic dipole interactions
- Cooperativity among charged structures (e.g., Fröhlich and Grodsky models)
- Ferromagnetic resonance (magnetite)
- Magnetic orientation of reactants
- Non-linear transmembrane responses
- Coherent long-range intermolecular interactions; non-linear dynamics
- Non-linear responses in the plane of the membrane and at membrane interfaces
- Stochastic resonance
- Synergistic excitatory or inhibitory effects with ionizing radiation & chemicals
- Amplification by biochemical cascades
- Altered receptor-ligand binding
- Absorption in water bound at cell surfaces
- Biasing field effects on intersystem crossing of charged singlet to triplet states and vice versa, resulting in changes in free radical concentrations
- Torque on electric or magnetic dipoles at cellular or molecular dimensions; e.g., electro-rotation

Research Gaps

Opportunities for future research on mechanisms with potential value for environmental exposures to RF energy include:

- Radical pair mechanisms in which field-driven conversion between triplet spin state ion pairs and singlet spin states can result in higher free-radical reaction rates for certain biological molecules.
- Similarly to free-radical pairs, there are reactions where intersystem ("forbidden") crossing of electronic spin states is possible. Such reactions have the following features:
  - Non-locality of entangled electrons perturbed by vanishing small field levels.
  - As already noted, RF photons below infrared frequencies can affect vibrational states (i.e., add heat), but cannot provide the quantum energy needed for direct molecular excitation. Therefore, if there are RF effects on molecular reactions, the RF energy must target an excited or metastable state through an effect on intersystem crossing.
  - Various cells can exhibit these potential targets: Active electron transport systems of mitochondria, chloroplasts; redox enzymes like mixed function oxidases (of the liver) or NAD(P)H oxidases of innate immune cells; nitric oxide synthases; ephaptic conduction in neuronal tissues (as opposed to ion-based saltatory conduction) found in CNS tissues (brain) and cryptochromes of the retina and chronobiological system (internal clock).

A recent panel identified these gaps concerning mechanisms (NRC, 2008):

- Effects of RF fields on biological neural networks and detection of low levels fields
- Evaluation of RF dose at the microscopic level
- Software based nonlinear cell models leading to molecular change

- Effects of RF on molecular and ion transport through cell membranes

This last item conflicts in part with statements above that RF fields oscillate too rapidly to affect transport processes directly.

Research Priorities

- **Pulsed versus continuous waves –** Sharpen understanding of mechanisms and biological effects that are specific to pulsed RF fields, specifically, studies of human EEG where effects on alpha rhythms have been reported (e.g., Croft et al. 2008 and for review, Juutilainen 2011).
- **Small thermal effects –** Study the effects and mechanisms of low-energy deposition that produces temperature changes smaller than an increase of 1˚C.
- **Effects on cryptochromes –** Evaluate the usefulness of cryptochromes for mechanistic studies of free radical chemistry. Cryptochromes are a class of blue -light-sensitive flavoproteins involved in the circadian rhythms of plants and animals, and in the sensing of magnetic fields in a number of species.

General Recommendations for RF Research Based on a Mechanistic Approach

- Design experimental protocols, including appropriate controls, from first principles of enzyme chemistry and photochemistry.
- Specifically, consider studies where S-T crossing in free-radical pairs may provide an observable outcome.
- Use mechanisms and, if possible, biomarkers to guide experimental and epidemiological designs in contrast to hypotheses based on speculative phenomena and mechanisms lacking ability to describe outcomes quantitatively.

3.8 Research Priorities

The workshop participants were asked to provide input on priorities for RF health research. Following identification and agreement on a long list of recommendations, participants were asked to reduce the list to no more than ten, and then to vote on prioritization. The results are summarized below.

Research Recommendations

Exposure Assessment

- **Exposure characterization –** Ascertain and characterize the broad and rapidly changing exposure environment from emerging RF-based technologies, ranging from mobile phones to smart grid metering, controls, and communication technology. As a baseline, exposure characterization should begin with "unperturbed fields," before the complexities of bodily interactions, absorbed energy, the placement of personal monitors on the body, and specific absorption rate (SAR) are considered.
- **High exposure populations –** Assess and measure the exposure environment for subpopulations working in high RF field environments, such as tower workers who maintain broadcast antennas and radar installations.
- **Conductive devices and clothing** – Study the effects of conductive devices in the body, such as implants, as well as metallic clothing on SAR at local tissue sites.
- **Exposure metrics –** Evaluate the usefulness, value, and propriety of various exposure metrics used in health effects research. Examples include time-weighted average fields, peak power, pulsed/modulated fields, frequency, RMS field, and SAR.
- **Mobile phone behavior –** Develop an exposure matrix that captures the changing usage patterns and behavior of mobile phone users as it relates to RF exposure. Determine how texting, ear buds, speaker phones, and new applications have impacted phone use. Determine how the move toward mobile computing is changing the nature and usage of smart phones.

Cellular/Mechanistic Studies

- **Small thermal effects –** Study the effects and mechanisms of small-scale energy deposition below the presumed hazard level of 1º C. What mechanisms are at work or triggered by small thermal effects?
- **Effects of cryptochrome –** Evaluate the usefulness of cryptochrome for mechanistic studies of free radical chemistry.

Animal Studies

- **Immature and juvenile animals –** Conduct studies on very young animals whose brains are in the developmental stages. Include studies that explore neurotoxicology, animal behavior, and functioning of the central nervous system.
- **Adult animals –** Extend current and future laboratory studies on adult animals to include brain cancer, multigenerational fertility, and behavior modification.
- **Animal dosimetry –** Improve the dosimetry used in laboratory experiments to better capture the nature, scale, and distribution of SAR on a localized scale.

Human Laboratory Studies

- **Susceptible sub-populations** – Identify subpopulations most susceptible to EEG effects of RF fields. Characterize and contrast the EEG effects with normal variation found in adults.
- **Positron emission tomography (PET)** – Use PET technology to study the brain during RF stimulation to help identify what functional correlates accompany the increase in alpha brain waves with modulated RF signals.
- **Mechanisms of EEG effects** – Explore underlying mechanisms of increases in brain activity due to RF exposures, including modulation frequency, potential demodulation mechanisms, localized effects, global effects, etc. What is the biophysical link? Why do the effects linger after exposure ceases, especially during sleep? What are the downstream effects of increased brain activity on behavior and cognition, and do such changes reveal or suggest underlying mechanisms?

Epidemiology

- **Brain cancer trends** – Monitor and study long-term incidence trends in brain cancer, as an ecological gross indicator of possible risks to across the population. Study the predictive value of such trends as RF sources continue to proliferate.
- **Children's phone use** – Study the behavioral aspects of phone use by children. How, when, and where do they use cell phone technology, and for what purpose? How does their exposure differ from adolescents and adults? Will generational usage patterns continue to evolve as the mobile phone morphs into the mobile computer?
- **Smart meter sensitivity** – Study the characteristics of individuals reporting sensitivity to smart meter operation. Study self-reporting accuracy in controlled laboratory testing of individual sensitivity.
- **Childhood brain cancer and leukemia** – Explore the possible association of cell phone use with childhood brain cancer and leukemia, using retrospective, case-control epidemiological study methodologies.
- **Policy studies** – Study policy dimensions of smart grid health concerns.
- **Sperm quality** – Use epidemiological techniques to study the association of mobile phone with deterioration in sperm quality.

Research Priorities

The participants winnowed the 20 recommendations down to a subset of 9 they felt were most appropriate to the present and future activities of the electric utility industry. Subsequently, they voted in a priority-setting exercise. The results are listed below in priority order.

1. **Exposure characterization –** Ascertain and characterize the broad and rapidly changing exposure environment from emerging RF-based technologies, ranging from mobile phones to smart grid metering, controls, and communication technology. As a baseline, exposure characterization should begin with "unperturbed fields," before the complexities of bodily interactions, absorbed energy, the placement of personal monitors on the body, and specific absorption rate (SAR) are considered.
2. **Mechanisms of EEG effects** – Explore underlying mechanisms of increases in brain wave activity due to RF exposures, including modulation frequency, potential demodulation mechanisms,, etc. What is the biophysical link? Why do the effects linger after exposure ceases, especially during sleep? What are the downstream effects of increased brain activity on behavior and cognition, and do such changes reveal or suggest underlying mechanisms?

3. **Effects of cryptochrome –** Evaluate the usefulness of cryptochrome for mechanistic studies of free radical chemistry.

4. **Immature and juvenile animals –** Conduct studies on very young animals whose brains are in the developmental stages. Include studies that explore neurotoxicology, animal behavior, and the functioning of the central nervous system.

5. **Small thermal effects –** Study the effects and mechanisms of small-scale energy deposition well below the presumed hazard level of 1°C. What mechanisms are at work or triggered by small thermal effects?

6. **Exposure metrics –** Evaluate the usefulness, value, and propriety of various exposure metrics used in health effects research. Examples include time-weighted average fields, peak power, pulsed/modulated fields, and frequency.

7. **Brain cancer trends** – Monitor and study long-term incidence trends in brain cancer, as an ecological gross indicator of possible risks across the population. Study the predictive value of such trends as RF sources continue to proliferate.

8. **Mobile phone behavior –** Develop an exposure matrix that captures the changing usage patterns and behavior of mobile phone users as it relates to RF exposure. How has texting, ear buds, speaker phones, and applications impacted phone use? How is the move toward mobile computing changing the nature and usage of smart phones?

9. **Susceptible sub-populations** – Identify subpopulations most susceptible to EEG effects engendered by RF fields. Characterize and contrast the EEG effects with normal variation found in adults.

Section 4: Bibliography

The following citations are indexed to the headings in Section 3 of this report as source material that can help the reader expand his/her familiarity with the issues covered in these workshops. It is not intended as an exhaustive list of all reference material, as the fields of health studies and technologies are vast.

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Appendix A: Agendas and Participants

AGENDA
Technology Workshop
Knoxville, TN
June 7, 2011

Time	**Topic**
7:30 – 8:00 am	Registration and Continental Breakfast
8:00 am – 8:30 am	Welcome/Overview – M. McGranaghan Agenda and Topical Summary Overview – D. Dorr
8:30 am – 9:00 am	The history of EPRI's exposure research and the big picture on health assessment of new Smart Grid technologies/exposure scenarios - G. Mezei
9:00 am – 9:30 am	Topic 1. Renewables and Distributed Energy Resources – T. Key, A Huque
9:30 am -10:00 am	Topic 2. Demand Response Controllable End Use Power Electronics - B. Fortenbery
10:00 am – 10:15 am	Morning Break
10:15 am – 10:45 am	Topic 3. Smart Grid Communication and Control Equipment – B. Green
10:45 am – 11:15 am	Topic 4. Electric Vehicles and Charging Infrastructure – J. Halliwell
11:15 am – 11:45 am	Topic 5. Advanced Metering Infrastructure – B. Seal
11:45 am – 12:30 pm	Electric Utility Perspectives – Invited Advisors
12:30 pm working lunch	Lunch Provided
12:45 – 3:00 pm	Working Session Part 1 Deep Dive and Gap Analysis for Topics 1-5
3:00 pm – 3:15 pm	Break
3:15 pm – 3:30 pm	Measurement Protocols and Discussion – P. Keebler
3:30 pm – 4:30 pm	Working Session Part II - Strategic Road Mapping Exercise
4:30 pm – 5:00pm	Closing Session – Recap and Follow on Plan of Action

PARTICIPANTS
Technology Workshop
Knoxville, TN
June 7, 2011

Present	
Name	**Affiliation**
Rob Kavet	EPRI
Brad Connatser	EPRI
Kim Craven	Duke Energy
Doug Dorr	EPRI
Brian Fortenbery	EPRI
Brian Green	EPRI
John Halliwell	EPRI
Aminul Huque	EPRI
Philip Keebler	EPRI
Tom Key	EPRI
Norm McCullough	EPRI
Gabor Mezei, M.D., Ph.D.	EPRI
Charles Perry	EPRI
Brian Seal	EPRI

Via Telephone	
Name	**Affiliation**
Sarah Mullen	EPRI
Scott Sternfeld	EPRI

AGENDA
RF Health Effects Workshop
Palo Alto, CA
July 12-13, 2011

Tuesday, July 12, 2011

Time	Topic	Presenter
8:00 a.m.	*Continental Breakfast*	
8:30 a.m.	Welcome and Introduction • Workshop Objectives • Organization • Expectations	*Chair: G. Mezei – EPRI* *Co-Chair: R. Kavet – EPRI*
9:10 a.m.	National Academy of Sciences Summary of Health Needs Related to Wireless Communication Devices	*F. Barnes*
9:30 a.m.	World Health Organization: Summary of RF Research Agenda	*E. Van Deventer*
9:50 a.m.	International Agency for Research on Cancer RF-EMF Working Group Meeting	*M. Roosli, D. McCormick*
10:10 a.m.	*Break*	
10:30 a.m.	Engineering Perspective: Relevant Electric Technologies In Electric Utilities	*D. Dorr*
11:00 a.m.	Exposure Assessment	*Presenter: R. Tell*

11:30 a.m.	Discussion
	• Exposure Assessment
	  ○ Dosimetry
	  ○ Source Characterization
	  ○ Exposure Studies
	  ○ Instrumentation
		Rapporteur: R. Olsen

12:00 p.m.	*Lunch*	
12:30 p.m.	Discussion continued	
1:30 p.m.	In vitro, Cellular and Mechanistic Studies	*Presenter: J. Kiel*
2:00 p.m.	Discussion • In vitro, Cellular and Mechanistic Studies	*Rapporteur: A. Sheppard*
3:00 p.m.	*Break*	
3:30 p.m.	Animal Laboratory Studies	*Presenter: D. McCormick*
4:00 pm	Discussion • Animal Laboratory Studies	*Rapporteur: Z. Sienkiewicz*
5:00 p.m.	Day 1 – Meeting Wrap-Up	*G. Mezei*
5:15 p.m.	Adjourn	
6:30 p.m.	Dinner, Cibo's Restaurant	

Wednesday, July 13, 2011

Time	Topic	Presenter
8:00 a.m.	*Continental Breakfast*	
8:30 a.m.	Introduction to Day 2 and Day 1 Recap	*G. Mezei*
9:00 a.m.	Human Laboratory Studies	*Presenter: S. Loughran*
9:30 a.m.	Discussion	*Rapporteur: R. Croft*
	• Human Laboratory Studies	
10:30 a.m.	*Break*	
11:00 a.m.	Epidemiology	*Presenter: M. Roosli*
11:30 a.m.	Discussion • Epidemiology	*Rapporteur: R. Neutra*
12:00 p.m.	*Lunch*	
12:30 p.m.	Discussion continued	
1:30 p.m.	Session Summaries - 1:30 pm: R. Olsen - 1:45 pm: A. Sheppard - 2:00 pm: Z. Sienkiewicz - 2:15 pm: R. Croft - 2:30 pm: R. Neutra	
2:45 p.m.	*Break*	
3:15 p.m.	Priority Setting and Next Steps	*G. Mezei*
5:00 p.m.	Adjourn	

ATTENDEES
RF Health Effects Workshop
Palo Alto, CA
July 12-13, 2011

Abdelmonem Afifi	UCLA School of Public Health
Frank Barnes	University of Colorado at Boulder
Bill Bruno	Los Alamos National Laboratory
Jerry Bushberg	University of California, Davis
Rodney Croft	University of Wollongong
Doug Dorr	EPRI
Richard Findlay	Health Protection Agency in the United Kingdom
Christopher Gordon	U.S. Environmental Protection Agency
Rob Kavet	EPRI
Leeka Kheifets	UCLA School of Public Health
Johnathan Kiel	BioAnalysis Consulting LLC
Sarah Loughran	University of Zurich
David McCormick	IIT Research Institute
Norman McCollough	EPRI
Gabor Mezei	EPRI
Raymond R. Neutra	Div of Environmental and Occupational Disease Control
Bob Olsen	College of Engineering and Architecture
Martin Roosli	Swiss Tropical and Public Health Institute
Asher Sheppard	Asher Sheppard Consulting
Zenon Sienkiewicz	Health Protection Agency
Mike Silva	EPRI
Ric Tell	Richard Tell Associates, Inc.
Paul Vaska	Brookhaven National Laboratory
Ximena Vergara	EPRI

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