IEEE Committee on Man and Radiation

COMAR Technical Information Statement

Human Exposure to Radio Frequency and Microwave Radiation from Portable and Mobile Telephones and Other Wireless Communication Devices

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Abstract

The Institute of Electrical and Electronics Engineers (IEEE) Committee on Man and Radiation (COMAR) recognizes that there is public concern about the safety of exposure to the radio frequency (RF) and microwave (MW) fields from hand-held, portable, and mobile cellular telephones.

Several national and international organizations have established guidelines for human exposure to radio frequency energy. These include the IEEE C95.1 standard [1] and the recommendations of the National Council on Radiation Protection and Measurements (NCRP) [2], the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [3] and the National Radiation Protection Board (NRPB) in the United Kingdom [4]. While these guidelines differ in some respects, their limits in the frequency range used by wireless communications devices are broadly similar. The consensus of the scientific community, as reflected in these exposure guidelines, is that exposure to RF energy below recommended limits in these guidelines is safe.

In the USA the Federal Communications Commission (FCC) authorizes the marketing of wireless communication devices that comply with its exposure guidelines [5]. The FCC guidelines, which are based on the NCRP exposure limits, were developed to protect workers and the general population from harmful exposure to RF fields and have been promulgated because of FCC legal responsibilities under the National Environmental Policy Act of 1969 (NEPA). European and other countries have their own specific requirements.

Measurements have shown that RF exposure to individuals from use of cellular telephones and other low power wireless transceivers is normally within recommended limits. Some cell phones and other wireless transceivers can affect the operation of heart pacemakers, implantable defibrillators, or other body-mounted medical devices, if the phone is placed directly next to the

devices (within a few centimeters). Individuals with such devices should follow their physicians' recommendations regarding safe use of wireless transceivers.

BACKGROUND

The use of cellular telephones has increased rapidly during the late 1990s. Newer wireless communication technologies also employ hand-held transceivers. These include specialized mobile radio (SMR) and personal communications services (PCS) (which are also cellular wireless systems). Currently there are over 80 million cellular phone users in the United States and its territories and possessions. The number of cellular phone users world-wide is estimated to reach 500 million by the year 2001 and 700 million by the year 2003.

This report addresses the concerns that have been expressed by some members of the public about the safety of exposure to radio frequency (RF) radiation from handheld communications devices, with particular reference to cellular telephone handsets.

When considering possible hazards from exposure to wireless transmitters, several considerations must be taken into account. The first consideration is frequency because exposure guidelines vary with frequency. Wireless communications operate in a variety of frequency ranges. In the USA, hand-held and mobile cellular telephones operate at frequencies between 824 and 849 MHz , while digital personal communication systems (PCS) operate in the 1850-1990 MHz band. Portable transceivers (such as "walkie-talkies") used for two-way communication typically operate near 30, 150 and 450 MHz. Cordless telephone units typically operate near 50, 915, or 2450 MHz.

A second consideration is the power output of the transmitter, and its distance from the body. Hand-held units (either cellular phones or other communications handsets) operate at comparatively low power levels but are used very close to the body. Mobile units operate at higher power levels, but their transmitting antennas are located some distance from their users.

A person's exposure to RF energy can be measured in several ways. For assessing exposure from transmitters located near the body, the most useful quantity is the specific absorption rate (SAR). SAR is a measure of the power absorbed in the body (either in a localized region of tissue or averaged over the whole body), expressed in units of watts per kilogram of tissue. The various exposure standards cited above are designed to limit the SAR in the body to safe levels.

RF Safety Standards and Guidelines

A number of organizations have established limits for human exposure to RF fields. These include the IEEE [1], the NCRP [2], the ICNIRP [3], and the United Kingdom National Radiation Protection Board (NRPB) [4]. (A table of acronyms and definitions is in the Appendix.) There are, in addition, various governmental limits that are usually based on these

standards. The different standards vary somewhat in their exposure limits and in other particulars. However, at frequencies used for wireless communications systems, these different guidelines are broadly similar.

Most of these guidelines specify two sets of limits, typically for occupational and non-occupational (general public) exposures. The IEEE-C95.1-1991 standard [1] distinguishes instead between "controlled" environments (any location where people are aware of a potential exposure) and "uncontrolled" environments. Most of these standards have limits for power density that are five times higher for controlled environments (or occupational exposure) than for uncontrolled environments (or for the general public) at frequencies up to 3,000 MHz.

All of these standards include provisions for different exposure situations. These include limits for whole-body exposure or partial body exposure (which is more relevant to users of wireless communications). The standards also require that the exposure be averaged over time periods ranging from 6-30 minutes [1] (which means that incidental exposures shorter than the averaging time can be higher than the limits). In addition, the IEEE standard has a "low power exclusion" that exempts low-powered devices from the necessity for exposure testing. (Most hand-held transceivers, including cellular handsets, fall within this exclusion.) Other guidelines (such as ICNIRP guidelines [3] and FCC guidelines) do not include such an exclusion.

All of these standards were developed by committees of scientists and engineers, who examined the scientific literature to identify potential hazards of RF exposure. Major standards were based on a comprehensive review of several thousand scientific papers, including engineering studies, whole-animal and cellular studies, and human (epidemiological) studies. The standards were approved only after a long review process involving a range of stakeholders including in many cases the general public.

Following their reviews of the scientific literature, most committees concluded that the most sensitive reproducible effect is the disruption of learned behavior in trained laboratory animals. This effect, which has been observed in several species of animals and under various RF exposure conditions, occurs at a whole-body SAR of about 4 W/kg. This RF energy absorption rate, which is associated with an increase in body temperature, stimulates the animal to stop performing a complex learned task. Such behavioral change is reversible and not considered harmful to the animal. The assumption is made, although not yet tested, that exposures at this level (same whole body SAR) would have comparable effects in humans. At considerably higher levels of exposure, thermal stress can occur that is similar to that produced by excessively hot environments or strenuous exercise.Despite a considerable amount of speculation in the scientific literature, no mechanism has been established by which electromagnetic fields at levels below recommended limits can produce biological damage of clinical consequence[6].

Only limited data are available about human exposures to RF energy, particularly long-term exposures. There have been a few studies involving the exposure of human subjects to RF energy similar to that emitted by cell phones, but no convincing evidence has emerged to indicate the potential for hazardous effects. An excellent review of the literature in this area has been given by Moulder et al. [7].

Two epidemiology studies have been published that bear on the question of a possible risk of brain cancer from the use of cell phones. Rothman and co-workers [8,9] have reported no differences in mortality between the users of hand-held portable phones (where the antenna is placed close to the head) and mobile cellular phones (where the antenna is mounted on the vehicle). Hardell et al [10,11], in a study of several hundred Swedish brain tumor patients, found no statistically significant associations between use of cell phones and brain cancer. It should be noted, however, that brain tumors (and other cancers) take many years to develop, far longer than the duration of exposure of most the subjects in these studies.

In summary, there is no evidence, from laboratory or epidemiology studies, that exposure to RF energy at levels below recommended limits has any health significance for humans.

Exposures Produced by Cellular Telephones

Cellular telephones used in the U.S. are required to operate within FCC guidelines. Those sold in Europe may have to comply with local guidelines, which in many countries are similar in nature but less restrictive than those of the FCC. Compliance is verified by experimental and/or theoretical assessment of the SARs produced by the phones in models of the head of the user. Because of the large safety factor incorporated into the standards, the regulatory limits are far below the anticipated thresholds for hazards.

Manufacturers in general design cellular phones that comply with regulatory limits, although at least one manufacturer has had to recall cellular phones because operating power levels were slightly higher than authorized and SAR levels were somewhat in excess of specified limits. Newer digital phones operate at lower average power levels than the older analog units, and are much less likely to exceed the exposure guidelines. Cordless telephones operating at 46 MHz use lower power levels than cell phones, and produce much less exposure to the user. However, newer cordless phones that operate at 900 MHz and 2.45 GHz use power levels that are comparable to conventional cell phones.

Interference to Medical Devices

Sufficiently high levels of RF energy can interfere with other electronic equipment [12]. This problem is more likely to occur with pulsed energy, which characterizes digital cellular telephones. Studies have shown that handheld cellular phones can affect the operation of heart pacemakers or defibrillators if the phone is placed directly over the device [12,13], and there have been reports of interference between cell phones and hearing aids. Individuals with pacemakers, implantable defibrillators, or other body-mounted medical electronic devices, should consult with their physician and/or the phone manufacturer to determine what precautions, if any, should be taken. Some manufacturers recommend that cell phones be used on the other side of the body from the implanted pacemaker.

Conclusions

Engineering data indicate that local SARs produced by hand-held, transportable, and mobile transceivers and cellular telephones normally do not exceed FCC and other safety limits. Present scientific evidence, as reviewed by standards setting organizations and other expert groups, does not demonstrate health or safety risks from cellular and other communications transceivers. A potential exists for interference between hand-held units and some medical devices that may be located in close proximity to them (within a few centimeters).

APPENDICES

FREQUENCIES AND OPERATING PROTOCOLS OF CELLULAR WIRELESS COMMUNICATION SYSTEMS

The early cellular networks used an analog transmission protocol (called frequency-division multiple access - FDMA), in which speech frequency modulates a continuous wave carrier. In the USA these cellular systems operate in the 824 - 894 MHz frequency range (824-849 MHz for the mobile/hand-helds and 869-894 MHz for the base stations), which was formerly allocated to UHF television channels 69-84.

At the beginning of the 1990s these systems were reaching the limits of their capacity in many service areas. This led to the introduction of new classes of cellular service using digital techniques, such as time-division multiple-access (TDMA), hybrid TDMA/FDMA, and more recently code-division multiple-access (CDMA). These digital systems operate in the same frequency band as the analog systems, but provide more voice channels per radio channel. In Europe, the most commonly used cellular system is called GSM (Global System for Mobile Communication), which is a hybrid TDMA/FDMA system, and operates in the 935-960 frequency band.

Personal Communication Services (PCS) is a newer wireless technology that operates in the 1800-2000 MHz band, using both TDMA and CDMA technologies. Compared with analog cellular systems, PCS systems operate at lower power levels, with more closely spaced cells and lower power handsets.

In the USA, the Federal Communications Commission originally authorized up to two cellular service providers per service area. However, to promote competition, new frequency bands have been created, and new services are being introduced. These include specialized mobile radio

(SMR) and enhanced specialized radio (ESMR), which operate at frequencies just below those used for cellular service. In addition, two PCS carriers are also licensed to operate in many regions of the United States.

Offsetting the increased number of wireless carriers, the progression of cellular technology from analog to digital systems with improved performance, has lead to a steady reduction of base station and phone transmitter powers. Additionally, modern systems are designed to reduce the power of both the base station and handset when the user is close to a base station, which further reduces average power levels.

For additional information about wireless telephone systems, readers are referred to discussions by Millington [14] and Rappaport [15].

GLOSSARY and ACRONYMS

ANSI - American National Standards Institute

EPA - (USA) Environmental Protection Agency

FDA - (USA) Food and Drug Administration

ICNIRP - International Commission on Non-Ionizing Radiation Protection

IEEE - The Institute of Electrical and Electronics Engineers

NCRP - National Council on Radiation Protection and Measurements

NIOSH - (USA) National Institute for Occupational Safety and Health

NRPB - National Radiation Protection Board (United Kingdom)

OSHA - (USA) Occupational Safety and Health Administration

Analog Communications Channel - A communication channel in which the message being transmitted, for example voice, directly modulates the amplitude or frequency of a higher frequency RF or MW signal.

CDMA (Code Division Multiple Access) - A method of coding the digitized messages of several users and transmitting them at the same time using a single communication channel. Each user's message is decoded independently of the others.

Cellular Phone System - A system for mobile wireless communication where blocks of frequencies (channels) can be reused by dividing a geographical area into hexagonal "cells" each of which contains a transmit/receive base station antenna. A mobile user within a cell communicates with the base station in that cell or an adjacent cell depending on the strength of the received signals. As the usermoves from cell to cell, the connection between the user and network is maintained by "handing-off" the user from one base station to another, i.e., switching to a channel assigned to that base station.

Digital Communication Channel - A communication channel in which the message is encoded as a series of "ones" and "zeros" (binary code). This can be done in several ways, but a common scheme has the phase of a component of the transmitted signal switched in discrete steps to represent the "zeros" and "ones," respectively.

Directional Antenna - An antenna that radiates energy efficiently in a specific direction. For example, the energy from directional antennas used for personal wireless service, often called "high-gain," "panel," or "sector" antennas, is usually propagated in a relatively narrow beam in the vertical plane (of the order of 10 degrees) and typically 120 degrees in the horizontal plane.

Downlink - The communication connection (transmitted signal) from a base station to a mobile station.

ERP (Effective Radiated Power) - A measure of how well an antenna concentrates the radiated energy in a specific direction. An analogy can be drawn in a comparison between an ordinary light bulb and a spotlight. At a given distance, the light that falls on a surface in the beam of a 100 W spotlight is much brighter than that from an ordinary 100 W bulb at the same distance, because the spotlight concentrates the light into a beam. Correspondingly, the light that falls on a surface that is not in the beam of the spotlight is much less than that from the ordinary light bulb at the same distance.

FDMA (Frequency Division Multiple Access) - A method for carrying multiple messages during a RF or MW transmission by encoding the messages of different users as modulations of different carrier frequencies.

GSM (Global System for Mobile Communications) - A hybrid TDMA/CDMA scheme widely used throughout Europe, and also becoming available in The USA.

High-Gain Antenna - an antenna whose radiation pattern is concentrated in a more or less narrow beam, i.e. a "directional antenna".

Microwatt (µW) - a power of one millionth of a watt.

Microwave (MW) - An electromagnetic wave with a wavelength between about one millimeter and 30 centimeters corresponding to a frequency between 300 GHz and 1 GHz.

Milliwatt (mW) - a power of one thousandth of a watt.

Omni-Directional Antenna - An antenna that radiates energy power more or less uniformly over an angle of 360 degrees in the horizontal plane around the antenna. Sometimes called a "low-gain" antenna. The familiar "whip" antennas are omnidirectional in their radiation patterns.

PCS (Personal Communication Service) - A term used by cellular service providers for digital service primarily in the 1800 - 2000 MHz frequency band. The term distinguishes this newer wireless protocol from cellular service at lower frequencies.

Power Flux - sometimes called "power density," is a measure of the radiated power reaching unit area of a surface. The accepted unit for this parameter is watts per square meter (W/m-sq). However, the older measure milliwatts per square centimeter (mW/cm-sq) is still encountered. 1 mW/cm-sq is equivalent to 10 W/m-sq.

Radio Frequency (RF) - frequencies of electromagnetic waves between approximately 3 kHz (3,000 Hz) and 300 GHz (3×10^{11} Hz). Sometimes, a distinction is drawn between radio waves, which have frequencies between 3 kHz and 1 GHz, and microwaves, which have a frequency between 1 GHz and 300 GHz.

SAR (Specific Absorption Rate) - A measure of the rate at which electromagnetic energy is absorbed by an exposed object. SAR, measured in watts per kilogram (W/kg), is the basic quantity from which modern RF and MW safety criteria (exposure limits) are derived.

TDMA (Time Division Multiple Access) - A method for combining the messages of several users on a single radio channel by assigning each user a different time segment of each transmit interval.

Transceiver - A term used to describe a communication device that can both receive (detect) signals, and transmit signals.

Uplink - The communication connection (transmitted signal) from a mobile station to a base station.

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