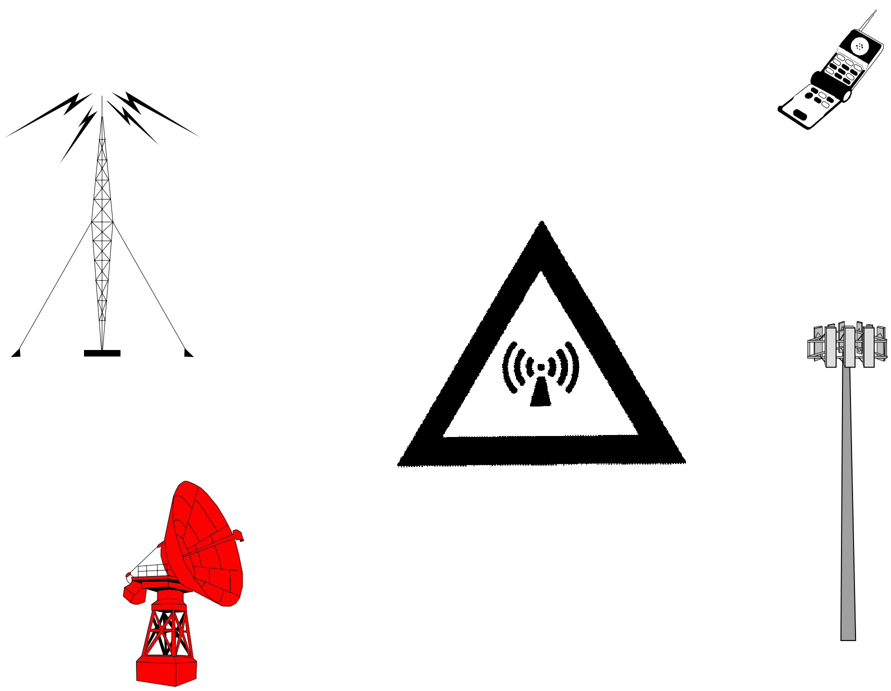
Federal Communications Commission
Office of Engineering & Technology

Questions and Answers about Biological Effects and Potential Hazards of Radiofrequency Electromagnetic Fields



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INTRODUCTION

Many consumer and industrial products and applications make use of some form of electromagnetic energy. One type of electromagnetic energy that is of increasing importance worldwide is radiofrequency (or "RF") energy, including radio waves and microwaves, which is used for providing telecommunications, broadcast and other services. In the United States the Federal Communications Commission (FCC) authorizes or licenses most RF telecommunications services, facilities, and devices used by the public, industry and state and local governmental organizations. Because of its regulatory responsibilities in this area the FCC often receives inquiries concerning whether there are potential safety hazards due to human exposure to RF energy emitted by FCC-regulated transmitters. Heightened awareness of the expanding use of RF technology has led some people to speculate that "electromagnetic pollution" is causing significant risks to human health from environmental RF electromagnetic fields. This document is designed to provide factual information and to answer some of the most commonly asked questions related to this topic.[1]

WHAT IS RADIOFREQUENCY ENERGY?

Radio waves and microwaves are forms of electromagnetic energy that are collectively described by the term "radiofrequency" or "RF." RF emissions and associated phenomena can be discussed in terms of "energy," "radiation" or "fields." Radiation is defined as the propagation of energy through space in the form of waves or particles. Electromagnetic "radiation" can best be described as waves of electric and magnetic energy moving together (i.e., radiating) through space as illustrated in **Figure 1.** These waves are generated by the movement of electrical charges such as in a conductive metal object or antenna. For example, the alternating movement of charge (i.e., the "current") in an antenna used by a radio or television broadcast station or in a cellular base station antenna generates electromagnetic waves that radiate away from the "transmit" antenna and are then intercepted by a "receive" antenna such as a rooftop TV antenna, car radio antenna or an antenna integrated into a hand-held device such as a cellular telephone. The term "electromagnetic field" is used to indicate the presence of electromagnetic energy at a given location. The RF field can be described in terms of the electric and/or magnetic field strength at that location.[2]

Like any wave-related phenomenon, electromagnetic energy can be characterized by a wavelength and a frequency. The wavelength (λ) is the distance covered by one complete

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[1] Exposure to low-frequency electromagnetic fields generated by electric power transmission has also been the subject of public concern. However, because the FCC does not have regulatory authority with respect to power-line electromagnetic fields, this document only addresses questions related to **RF** exposure. Information about exposure due to electrical power transmission can be obtained from several sources, including the following Internet World Wide Web site: **http://www.niehs.nih.gov/emfrapid**

[2] The term "EMF" is often used to refer to electromagnetic fields, in general. It can be used to refer to either power-line frequency fields, radiofrequency electromagnetic fields or both.

electromagnetic wave cycle, as shown in **Figure 1**. The frequency is the number of electromagnetic waves passing a given point in one second. For example, a typical radio wave transmitted by an FM radio station has a wavelength of about three (3) meters and a frequency of about 100 million cycles (waves) per second or "100 MHz." One "hertz" (abbreviated "Hz") equals one cycle per second. Therefore, in this case, about 100 million RF electromagnetic waves would be transmitted to a given point every second.

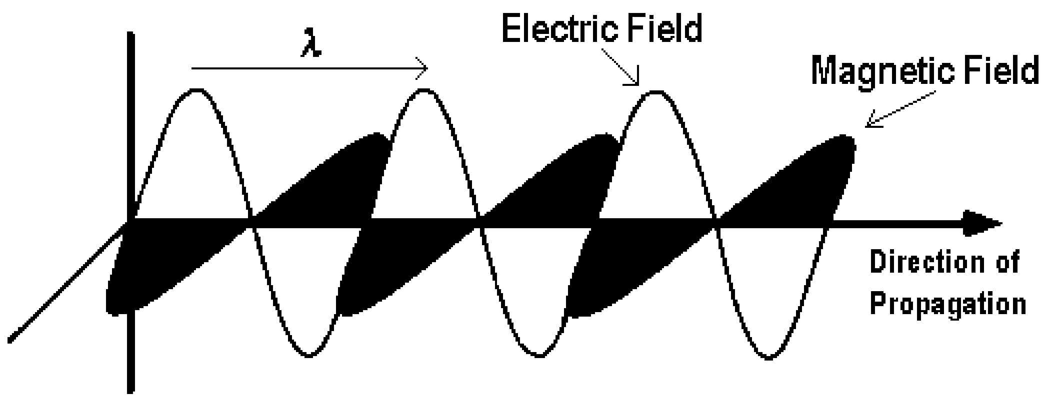

FIGURE 1. ***Electromagnetic Wave***

Electromagnetic waves travel through space at the speed of light, and the wavelength and frequency of an electromagnetic wave are inversely related by a simple mathematical formula: frequency (f) times wavelength (λ) = the speed of light (c), or $f \times \lambda = c$. This simple equation can also be expressed as follows in terms of either frequency or wavelength:

$$f = \frac{c}{\lambda} \quad or \quad \lambda = \frac{c}{f}$$

Since the speed of light in a given medium or vacuum does not change, high-frequency electromagnetic waves have short wavelengths and low-frequency waves have long wavelengths. The electromagnetic "spectrum" (**Figure 2**) includes all the various forms of electromagnetic energy from extremely low frequency (ELF) energy, with very long wavelengths, to X-rays and gamma rays, which have very high frequencies and correspondingly short wavelengths. In between these extremes are radio waves, microwaves, infrared radiation, visible light, and ultraviolet radiation, in that order. The RF part of the electromagnetic spectrum is generally defined as that part of the spectrum where electromagnetic waves have frequencies in the range of about 3 kilohertz to 300 gigahertz. One kilohertz (kHz) equals one thousand hertz, one megahertz (MHz) equals one million hertz, and one gigahertz (GHz) equals one billion hertz. Thus, when you tune your FM radio to 101.5, it means that your radio is receiving signals from a radio station emitting radio waves at a frequency of 101.5 million cycles (waves) per second, or 101.5 MHz.

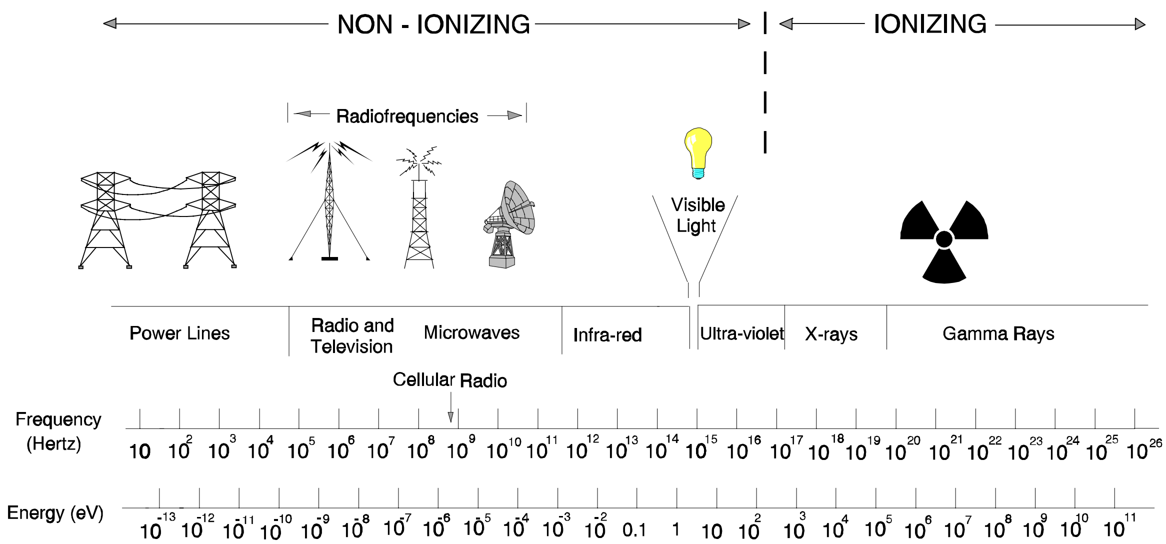

FIGURE 2. ***The Electromagnetic Spectrum***

HOW DO WE USE RADIOFREQUENCY ENERGY?

Probably the most important use for RF energy is in providing telecommunications services to the public, industry and government. Radio and television broadcasting, cellular telephones, personal communications services (PCS), pagers, cordless telephones, business radio, radio communications for police and fire departments, amateur radio, microwave point-to-point radio links and satellite communications are just a few of the many applications of RF energy for telecommunications.

Microwave ovens and radar are examples of non-communications uses of RF energy. Also important are uses of RF energy in industrial heating and sealing where electronic devices generate RF radiation that rapidly heats the material being processed in the same way that a microwave oven cooks food. RF heaters and sealers have many uses in industry, including molding plastic materials, gluing wood products, sealing items such as shoes and pocketbooks, and processing food products.

There are a number of medical applications of RF energy, including a technique called *diathermy*, that take advantage of the ability of RF energy to rapidly heat tissue below the body's surface. Tissue heating ("hyperthermia") can be beneficial in the therapeutic treatment of injured tissue and cancerous tumors (*see* References 17 & 18).

WHAT ARE MICROWAVES?

Microwaves are a specific category of radio waves that can be defined as radiofrequency radiation where frequencies range upward from several hundred megahertz (MHz) to several gigahertz (GHz). One of the most familiar and widespread uses of microwave energy is found in household microwave ovens, which operate at a frequency of 2450 MHz (2.45 GHz).

Microwaves are also widely used for telecommunications purposes such as for cellular radio, personal communications services (PCS), microwave point-to-point communication, transmission links between ground stations and orbiting satellites, and in certain broadcasting operations such as studio-to-transmitter (STL) and electronic news gathering (ENG) radio links. Microwave radar systems provide information on air traffic and weather and are extensively used in military and police applications. In the medical field microwave devices are used for a variety of therapeutic purposes including the selective heating of tumors as an adjunct to chemotherapy treatment (microwave hyperthermia).

Radiofrequency radiation, especially at microwave frequencies, efficiently transfers energy to water molecules. At high microwave intensities the resulting energetic water molecules can generate heat in water-rich materials such as most foods. The operation of microwave ovens is based on this principle. This efficient absorption of microwave energy via water molecules results in rapid heating throughout an object, thus allowing food to be cooked more quickly than in a conventional oven.

WHAT IS NON-IONIZING RADIATION?

As explained earlier, electromagnetic radiation is defined as the propagation of energy through space in the form of waves or particles. Some electromagnetic phenomena can be most easily described if the energy is considered as waves, while other phenomena are more readily explained by considering the energy as a flow of particles or "photons." This is known as the "wave-particle" duality of electromagnetic energy. The energy associated with a photon, the elemental unit of an electromagnetic wave, depends on its frequency (or wavelength). The higher the frequency of an electromagnetic wave (and the shorter its corresponding wavelength), the greater will be the energy of a photon associated with it. The energy content of a photon is often expressed in terms of the unit "electron-volt" or "eV".

Photons associated with X-rays and gamma rays (which have very high electromagnetic frequencies) have a relatively large energy content. At the other end of the electromagnetic spectrum, photons associated with low-frequency waves (such as those at ELF frequencies) have many times less energy. In between these extremes ultraviolet radiation, visible light, infrared radiation, and RF energy (including microwaves) exhibit intermediate photon energy content. For comparison, the photon energies associated with high-energy X-rays are billions of times ***more*** energetic than the energy of a 1-GHz microwave photon. The photon energies associated with the various frequencies of the electromagnetic spectrum are shown in the lower scale of **Figure 2**.

Ionization is a process by which electrons are stripped from atoms and molecules. This process can produce molecular changes that can lead to damage in biological tissue, including effects on DNA, the genetic material. This process requires interaction with photons containing high energy levels, such as those of X-rays and gamma rays. A single quantum event (absorption of an X-ray or gamma-ray photon) can cause ionization and subsequent biological damage due to the high energy content of the photon, which would be in excess of 10 eV (considered to be the minimum photon energy capable of causing ionization). Therefore, X-rays and gamma rays are examples of ***ionizing*** radiation. Ionizing radiation is also associated with the generation of nuclear energy, where it is often simply referred to as "radiation."

The photon energies of RF electromagnetic waves are not great enough to cause the ionization of atoms and molecules and RF energy is, therefore, characterized as ***non-ionizing*** radiation, along with visible light, infrared radiation and other forms of electromagnetic radiation with relatively low frequencies. It is important that the terms "ionizing" and "non-ionizing" not be confused when discussing biological effects of electromagnetic radiation or energy, since the mechanisms of interaction with the human body are quite different.

HOW ARE RADIOFREQUENCY FIELDS MEASURED?

Because an RF electromagnetic field has both an electric and a magnetic component (electric field and magnetic field), it is often convenient to express the intensity of the RF field in terms of units specific for each component. The unit "volts per meter" (V/m) is often used to measure the strength ("field strength") of the electric field, and the unit "amperes per meter" (A/m) is often used to express the strength of the magnetic field.

Another commonly used unit for characterizing an RF electromagnetic field is "power density." Power density is most accurately used when the point of measurement is far enough away from the RF emitter to be located in what is commonly referred to as the "far-field" zone of the radiation source, e.g., more than several wavelengths distance from a typical RF source. In the far field, the electric and magnetic fields are related to each other in a known way, and it is only necessary to measure one of these quantities in order to determine the other quantity or the power density. In closer proximity to an antenna, i.e., in the "near-field" zone, the physical relationships between the electric and magnetic components of the field are usually complex. In this case, it is necessary to determine both the electric and magnetic field strengths to fully characterize the RF environment. (Note: In some cases equipment used for making field measurements displays results in terms of "far-field equivalent" power density, even though the measurement is being taken in the near field.) At frequencies above about 300 MHz it is usually sufficient to measure only the electric field to characterize the RF environment if the measurement is not made too close to the RF emitter.

Power density is defined as power per unit area. For example, power density can be expressed in terms of milliwatts per square centimeter (mW/cm^2) or microwatts per square centimeter ($\mu W/cm^2$). One mW equals 0.001 watt of power, and one µW equals 0.000001 watt. With respect to frequencies in the microwave range and higher, power density is usually used to express intensity since exposures that might occur would likely be in the far-field. More details about the physics of RF fields and their analysis and measurement can be found in References 2, 3, 8, 21, 33, 34 and 35.

WHAT BIOLOGICAL EFFECTS CAN BE CAUSED BY RF ENERGY?

A biological effect occurs when a change can be measured in a biological system after the introduction of some type of stimuli. However, the observation of a biological effect, in and of itself, does not necessarily suggest the existence of a biological ***hazard***. A biological effect only becomes a safety hazard when it "causes detectable impairment of the health of the individual or of his or her offspring" (Reference 25).

There are many published reports in the scientific literature concerning possible biological effects resulting from animal or human exposure to RF energy. The following discussion only provides highlights of current knowledge, and it is not meant to be a complete review of the scientific literature in this complex field. A number of references are listed at the end of this document that provide further information and details concerning this topic and some recent research reports that have been published (References 1, 3, 6, 7, 9, 14, 15-19, 21, 25, 26, 28-31, 34, 36, 39-41, 47, 49 and 53).

Biological effects that result from heating of tissue by RF energy are often referred to as "thermal" effects. It has been known for many years that exposure to high levels of RF radiation can be harmful due to the ability of RF energy to heat biological tissue rapidly. This is the principle by which microwave ovens cook food, and exposure to very high RF power densities, i.e., on the order of 100 mW/cm^2 or more, can clearly result in heating of biological tissue and an increase in body temperature. Tissue damage in humans could occur during exposure to high RF levels because of the body's inability to cope with or dissipate the excessive heat that could be generated. Under certain conditions, exposure to RF energy at power density levels of 1-10 mW/cm^2 and above can result in measurable heating of biological tissue (but not necessarily tissue damage). The extent of this heating would depend on several factors including radiation frequency; size, shape, and orientation of the exposed object; duration of exposure; environmental conditions; and efficiency of heat dissipation.

Two areas of the body, the eyes and the testes, are known to be particularly vulnerable to heating by RF energy because of the relative lack of available blood flow to dissipate the excessive heat load (blood circulation is one of the body's major mechanisms for coping with excessive heat). Laboratory experiments have shown that short-term exposure (e.g., 30 minutes to one hour) to very high levels of RF radiation (100-200 mW/cm^2) can cause cataracts in rabbits. Temporary sterility, caused by such effects as changes in sperm count and in sperm motility, is possible after exposure of the testes to high-level RF radiation (or to other forms of energy that produce comparable increases in temperature).

Studies have shown that environmental levels of RF energy routinely encountered by the general public are *far below* levels necessary to produce significant heating and increased body temperature (References 32, 37, 45, 46, 48 and 54). However, there may be situations, particularly workplace environments near high-powered RF sources, where recommended limits for safe exposure of human beings to RF energy could be exceeded. In such cases, restrictive measures or actions may be necessary to ensure the safe use of RF energy.

In addition to intensity, the frequency of an RF electromagnetic wave can be important in determining how much energy is absorbed and, therefore, the potential for harm. The quantity used to characterize this absorption is called the "specific absorption rate" or "SAR," and it is usually expressed in units of watts per kilogram (W/kg) or milliwatts per gram (mW/g). In the far-field of a source of RF energy (e.g., several wavelengths distance from the source) whole-body absorption of RF energy by a standing human adult has been shown to occur at a maximum rate when the frequency of the RF radiation is between about 80 and 100 MHz, depending on the size, shape and height of the individual. In other words, the SAR is at a maximum under these conditions. Because of this "resonance" phenomenon, RF safety standards have taken account of the frequency dependence of whole-body human absorption, and the most restrictive limits on exposure are found in this frequency range (the very high frequency or "VHF" frequency range).

Although not commonly observed, a microwave "hearing" effect has been shown to occur under certain very specific conditions of frequency, signal modulation, and intensity where animals and humans may perceive an RF signal as a buzzing or clicking sound. Although a number of theories have been advanced to explain this effect, the most widely-accepted hypothesis is that the microwave signal produces thermoelastic pressure within the head that is perceived as sound by the auditory apparatus within the ear. This effect is not recognized as a health hazard, and the conditions under which it might occur would rarely be encountered by members of the public. Therefore, this phenomenon should be of little concern to the general population. Furthermore, there is no evidence that it could be caused by telecommunications applications such as wireless or broadcast transmissions.

At relatively low levels of exposure to RF radiation, i.e., field intensities lower than those that would produce significant and measurable heating, the evidence for production of harmful biological effects is ambiguous and unproven. Such effects have sometimes been referred to as "non-thermal" effects. Several years ago publications began appearing in the scientific literature, largely overseas, reporting the observation of a wide range of low-level biological effects. However, in many of these cases further experimental research was unable to reproduce these effects. Furthermore, there has been no determination that such effects might indicate a human health hazard, particularly with regard to long-term exposure.

More recently, other scientific laboratories in North America, Europe and elsewhere have reported certain biological effects after exposure of animals ("*in vivo*") and animal tissue ("*in vitro*") to relatively low levels of RF radiation. These reported effects have included certain changes in the immune system, neurological effects, behavioral effects, evidence for a link between microwave exposure and the action of certain drugs and compounds, a "calcium efflux" effect in brain tissue (exposed under very specific conditions), and effects on DNA.

Some studies have also examined the possibility of a link between RF and microwave exposure and cancer. Results to date have been inconclusive. While some experimental data have suggested a possible link between exposure and tumor formation in animals exposed under certain specific conditions, the results have not been independently replicated. In fact, other studies have failed to find evidence for a causal link to cancer or any related condition. Further research is underway in several laboratories to help resolve this question.

In general, while the possibility of "non-thermal" biological effects may exist, whether or not such effects might indicate a human health hazard is not presently known. Further research is needed to determine the generality of such effects and their possible relevance, if any, to human health. In the meantime, standards-setting organizations and government agencies continue to monitor the latest experimental findings to confirm their validity and determine whether alterations in safety limits are needed in order to protect human health.

WHAT RESEARCH IS BEING DONE ON RF BIOLOGICAL EFFECTS?

For many years research into possible biological effects of RF energy has been carried out in government, academic and industrial laboratories all over the world, and such research is continuing. Past research has resulted in a very large number of scientific publications on this topic, some of which are listed in the reference section of this document. For many years the U.S. Government has sponsored research into the biological effects of RF energy. The majority of this work has been funded by the Department of Defense, due, in part, to the extensive military interest in using RF equipment such as radar and other relatively high-powered radio transmitters for routine military operations. In addition, some U.S. civilian federal agencies responsible for health and safety, such as the Environmental Protection Agency (EPA) and the U.S. Food and Drug Administration (FDA), have sponsored and conducted research in this area in the past, although relatively little civilian-sector RF research is currently being funded by the U.S. Government. At the present time, much of the non-military research on biological effects of RF energy in the U.S. is being funded by industry organizations such as Motorola, Inc. In general, relatively more research is being carried out overseas, particularly in Europe.

In 1996, the World Health Organization (WHO) established a program (the International EMF Project) designed to review the scientific literature concerning biological effects of electromagnetic fields, identify gaps in knowledge about such effects, recommend research needs, and work towards international resolution of health concerns over the use of RF technology. (*see* Reference 40) The WHO and other organizations maintain Internet Web sites that contain additional information about their programs and about RF biological effects and research (see list of Web sites in **Table 3** of this bulletin). The FDA, the EPA and other federal agencies responsible for public health and safety are working with the WHO and other organizations to monitor developments and identify research needs related to RF biological effects. For example, in 1995 the EPA published the results of a conference it sponsored to assess the current state of knowledge of RF biological effects and to address future research needs in this area (Reference 53).

WHAT LEVELS ARE SAFE FOR EXPOSURE TO RF ENERGY?

Development of Exposure Guidelines

Exposure standards and guidelines have been developed by various organizations and countries over the past several decades. In North America and most of Europe exposure standards and guidelines have generally been based on exposure levels where effects considered harmful to humans occur. Safety factors are then incorporated to arrive at specific levels of exposure to provide sufficient protection for various segments of the population.

Not all standards and guidelines throughout the world have recommended the same limits for exposure. For example, some published exposure limits in Russia and some eastern European countries have been generally more restrictive than existing or proposed recommendations for exposure developed in North America and other parts of Europe. This discrepancy may be due, at least in part, to the possibility that these standards were based on exposure levels where it was believed no biological effects *of any type* would occur. This philosophy is inconsistent with the approach taken by most other standards-setting bodies which base limits on levels where recognized hazards may occur and then incorporate appropriate safety margins to ensure adequate protection.

In the United States, although the Federal Government has never itself developed RF exposure standards, the FCC has adopted and used recognized safety guidelines for evaluating RF environmental exposure since 1985. Federal health and safety agencies, such as the Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) have also been actively involved in monitoring and investigating issues related to RF exposure. For example, the FDA has issued guidelines for safe RF emission levels from microwave ovens, and it continues to monitor exposure issues related to the use of certain RF devices such as cellular telephones. NIOSH conducts investigations and health hazard assessments related to occupational RF exposure.

In 1971, a federal RF radiation protection guide for workers was issued by OSHA based on the 1966 American National Standards Institute (ANSI) RF exposure standard. However, the OSHA regulation was later ruled to be advisory only and not enforceable. Presently, OSHA enforcement actions related to RF exposure of workers are undertaken using OSHA's "general duty clause," which relies on the use of widely-supported voluntary "consensus" standards such as those discussed below.[3]

U.S. federal, state and local governmental agencies and other organizations have generally relied on RF exposure standards developed by expert non-government organizations such as ANSI, the Institute of Electrical and Electronics Engineers (IEEE) and the National Council on Radiation Protection and Measurements (NCRP).[4] For example, in 1966, 1974, and 1982, ANSI issued protection guides for RF exposure developed by committees of experts. These earlier ANSI standards recommended limits for exposure of the public that were the same as those recommended for exposure of workers.

In 1986, the NCRP issued exposure criteria for the workplace that were the same as the 1982 ANSI recommended levels, but the NCRP also recommended more restrictive limits for exposure of the general public. Therefore, the NCRP exposure criteria included ***two*** tiers of recommended limits, one for the general population and another for occupational exposure. In 1987, the ANSI committee on RF exposure standards (Standards Coordinating Committee 28) became a committee of the IEEE, and, in 1991, revised its earlier standard and issued its own two-tiered standard that had been developed over a period of several years.

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[3] For information about OSHA RF-related activities and RF protection programs for workers, see the OSHA Internet Web site (case sensitive): www.osha-slc.gov/SLTC/ (select subject: "radiofrequency radiation").

[4] ANSI is a non-profit, privately funded, membership organization that coordinates development of voluntary national standards. The IEEE is a non-profit technical and professional engineering society. The NCRP is a non-profit corporation chartered by the U.S. Congress to develop information and recommendations concerning radiation protection. Several government agencies, including the FCC, and non-government organizations have established relationships with NCRP as "Collaborating Organizations."

The ANSI/IEEE standards have been widely used and cited and have served as the basis for similar standards in the United States and in other countries. Both the NCRP and ANSI/IEEE guidelines were developed by scientists and engineers with a great deal of experience and knowledge in the area of RF biological effects and related issues. These individuals spent a considerable amount of time evaluating published scientific studies relevant to establishing safe levels for human exposure to RF energy.

In addition to NCRP and ANSI/IEEE, other organizations and countries have issued exposure guidelines. For example, several European countries are basing guidelines on exposure criteria developed by the International Committee on Nonionizing Radiation Protection (ICNIRP, Reference 25). The ICNIRP guidelines are also derived from an SAR threshold of 4 W/kg (for adverse effects) and are similar to the 1992 ANSI/IEEE and NCRP recommendations with certain exceptions. For example, ICNIRP recommends somewhat different exposure levels in the lower and upper frequency ranges and for localized exposure due to such devices as hand-held cellular telephones. Many, but not all, countries have based exposure recommendations on the same general concepts and thresholds as those used by the NCRP, ANSI/IEEE and ICNIRP. Because of differences in international standards, the World Health Organization (WHO), as part of its EMF Project (discussed earlier), has initiated a program to try and develop an international framework for RF safety standards.

FCC Exposure Guidelines

In 1985, the FCC adopted the 1982 ANSI guidelines for purposes of evaluating exposure due to RF transmitters licensed and authorized by the FCC. This decision was in response to provisions of the National Environmental Policy Act of 1969 requiring all Federal Government agencies to evaluate the impact of their actions on the "quality of the human environment."[5] In 1992, ANSI adopted the 1991 IEEE standard as an American National Standard (a revision of its 1982 standard) and designated it ANSI/IEEE C95.1-1992.[6]

In 1993, the FCC proposed to update its rules and adopt the new ANSI/IEEE guidelines. After a lengthy period to allow for the filing of comments and for deliberation the FCC decided, in 1996, to adopt a modified version of its original proposal.[7] The FCC's

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[5] The National Environmental Policy Act of 1969, 42 USC Section 4321, *et seq.*

[6] ANSI/IEEE C95.1-1992 (originally issued as IEEE C95.1-1991), "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz," (Reference 3).

[7] *See Report and Orde*r and *Second Memorandum Opinion and Order and Notice of Proposed Rulemaking*, ET Docket 93-62, (References 55 and 56). In 1997, the FCC released a technical bulletin entitled, "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields," OET Bulletin 65 (Reference 57) that contains detailed information on methods for compliance with FCC guidelines. These documents can be accessed at the FCC's Web site: **http://www.fcc.gov/oet/rfsafety.**

action also fulfilled requirements of the Telecommunications Act of 1996 for adopting new RF exposure guidelines.[8]

The FCC considered a large number of comments submitted by industry, government agencies and the public. In particular, the FCC considered comments submitted by the EPA, FDA, NIOSH and OSHA, which have primary responsibility for health and safety in the Federal Government. The guidelines the FCC adopted were based on the recommendations of those agencies, and they have sent letters to the FCC supporting its decision and endorsing the FCC's guidelines as protective of public health.

In its 1996 Order, the FCC noted that research and analysis relating to RF safety and health is ongoing and changes in recommended exposure limits may occur in the future as knowledge increases in this field. In that regard, the FCC will continue to cooperate with industry and with expert agencies and organizations with responsibilities for health and safety in order to ensure that the FCC's guidelines continue to be appropriate and scientifically valid.

The FCC's guidelines are based on recommended exposure criteria issued by the NCRP and ANSI/IEEE. The NCRP exposure guidelines are similar to the ANSI/IEEE 1992 guidelines except for differences in recommended exposure levels at the lower frequencies and higher frequencies of the RF spectrum. Both ANSI/IEEE and NCRP recommend two different tiers of exposure limits. The NCRP designates one tier for occupational exposure and the other for exposure of the general population while ANSI/IEEE designates exposure tiers in terms of "environments," one for "controlled" environments and the other for "uncontrolled" environments. Over a broad range of frequencies, NCRP exposure limits for the public are generally one-fifth those for workers in terms of power density.[9]

The NCRP and ANSI/IEEE exposure criteria identify the same threshold level at which harmful biological effects may occur, and the values for Maximum Permissible Exposure (MPE) recommended for electric and magnetic field strength and power density in

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[8] The Telecommunications Act of 1996, enacted on February 8, 1996, required that: "Within 180 days after the enactment of this Act, the Commission shall complete action in ET Docket 93-62 to prescribe and make effective rules regarding the environmental effects of radio frequency emissions." *See* Section 704(b) of the Telecommunications Act of 1996, Pub. L. No. 104-104, 110 Stat. 56 (1996).

[9] The FCC adopted limits for field strength and power density that are based on Sections 17.4.1 and 17.4.2, and the time-averaging provisions of Sections 17.4.1.1 and 17.4.3, of "Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields," NCRP Report No. 86, for frequencies between 300 kHz and 100 GHz (Reference 34). With the exception of limits on exposure to power density above 1500 MHz, and limits for exposure to lower frequency magnetic fields, these MPE limits are also based on the guidelines developed by the IEEE and adopted by ANSI. *See* Section 4.1 of ANSI/IEEE C95.1-1992, "Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz" (Reference 3).

both documents are based on this threshold level.[10] In addition, both the ANSI/IEEE and NCRP guidelines are frequency dependent, based on findings (discussed earlier) that whole-body human absorption of RF energy varies with the frequency of the RF signal. The most restrictive limits on exposure are in the frequency range of 30-300 MHz where the human body absorbs RF energy most efficiently when exposed in the far field of an RF transmitting source. Although the ANSI/IEEE and NCRP guidelines differ at higher and lower frequencies, at frequencies used by the majority of FCC licensees the MPE limits are essentially the same regardless of whether ANSI/IEEE or NCRP guidelines are used.

Most radiofrequency safety limits are defined in terms of the electric and magnetic field strengths as well as in terms of power density. For lower frequencies, limits are more meaningfully expressed in terms of electric and magnetic field strength values, and the indicated power densities are actually "far-field equivalent" power density values. The latter are listed for comparison purposes and because some instrumentation used for measuring RF fields is calibrated in terms of far-field or plane-wave equivalent power density. At higher frequencies, and when one is actually in the "far field" of a radiation source, it is usually only necessary to evaluate power density. In the far field of an RF transmitter power density and field strength are related by standard mathematical equations.[11]

The exposure limits adopted by the FCC in 1996 expressed in terms of electric and magnetic field strength and power density for transmitters operating at frequencies from 300 kHz to 100 GHz are shown in **Table 1**. The FCC also adopted limits for localized ("partial body") absorption in terms of SAR, shown in **Table 2**, that apply to certain portable transmitting devices such as hand-held cellular telephones.[12]

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[10] These exposure limits are based on criteria quantified in terms of specific absorption rate (SAR). SAR is a measure of the rate at which the body absorbs RF energy. Both the ANSI/IEEE and NCRP exposure criteria are based on a determination that potentially harmful biological effects can occur at an SAR level of 4 W/kg as averaged over the whole-body. Appropriate safety factors have been incorporated to arrive at limits for both whole-body exposure (0.4 W/kg for "controlled" or "occupational" exposure and 0.08 W/kg for "uncontrolled" or "general population" exposure, respectively) and for partial-body (localized SAR), such as might occur in the head of the user of a hand-held cellular telephone. The new MPE limits are more conservative in some cases than the limits specified by ANSI in 1982. However, these more conservative limits do not arise from a fundamental change in the SAR threshold for harm, but from a precautionary desire to add an additional margin of safety for exposure of the public or exposure in "uncontrolled' environments.

[11] See OET Bulletin 65 (Reference 57) for details.

[12] These guidelines are based on those recommended by ANSI/IEEE and NCRP. *See* Sections 4.2.1 and 4.2.2 of ANSI/IEEE C95.1-1992 and Section 17.4.5 of NCRP Report No. 86. For purposes of evaluation, the FCC has designated these devices as either "portable" or "mobile" depending on how they are to be used. Portable devices are normally those used within 20 centimeters of the body and must be evaluated with respect to SAR limits. Mobile devices are normally used 20 centimeters or more away from the body and can be evaluated in terms of either SAR or field intensity. Detailed information on FCC requirements for evaluating portable and mobile devices can be found in OET Bulletin 65 and in the FCC's Rules and Regulations, 47 CFR 2.1091 and 2.1093.

Time Averaging of Exposure

The NCRP and ANSI/IEEE exposure criteria and most other standards specify ***"time-averaged"*** MPE limits. This means that it is permissible to exceed the recommended limits for short periods of time as long as the ***average*** exposure (over the appropriate period specified) does not exceed the limit. For example, Table 1 shows that for a frequency of 100 MHz the recommended power density limit is 1 mW/cm^2 with an averaging time of six minutes (any six-minute period) for occupational/controlled exposure.

The time-averaging concept can be illustrated as follows for exposure in a workplace environment. The sum of the product (or products) of the actual exposure level(s) multiplied by the actual time(s) of exposure must not be greater than the allowed (average) exposure limit times the specified averaging time. Therefore, for 100 MHz, exposure at 2 mW/cm^2 would be permitted for three minutes in any six-minute period as long as during the remaining three minutes of the six-minute period the exposure was at or near "zero" level of exposure. Therefore, in this example:

$$\mathbf{(2\ mW/cm^2)\ X\ (3\ min.) + (0\ mW/cm^2)\ X\ (3\ min.) = (1\ mW/cm^2)\ X\ (6\ min.)}$$

Of course, other combinations of power density and time are possible. It is *very important* to remember that time averaging of exposure is only necessary or relevant for situations where temporary exposures might occur that are *in excess of* the absolute limits for power density or field strength. These situations usually only occur in workplace environments where exposure can be monitored and controlled. For general population/uncontrolled exposures, say in a residential neighborhood, it is seldom possible to have sufficient information or control regarding how long people are exposed, and averaging of exposure over the designated time period (30 minutes) is normally not appropriate. For such public exposure situations, the MPE limits normally apply for continuous exposure. In other words, as long as the absolute limits are not exceeded, indefinite exposure is allowed.

Induced and Contact Currents

In addition to limits on field strength, power density and SAR, some standards for RF exposure have incorporated limits for currents induced in the human body by RF fields. For example, the 1992 ANSI/IEEE standard (Reference 3), includes specific restrictions that apply to "induced" and "contact" currents (the latter, which applies to "grasping" contact, is more related to shock and burn hazards). The limits on RF currents are based on experimental data showing that excessive SAR levels can be created in the body due to the presence of these currents. In its 1996 Order adopting new RF exposure guidelines the FCC declined to adopt limits on induced and contact currents due primarily to the difficulty of reliably determining compliance, either by prediction methods or by direct measurement. However, the FCC may reconsider this decision in the future because of the development of new instrumentation and analytical techniques that may be more reliable indicators of exposure.

Table 1. *FCC Limits for Maximum Permissible Exposure (MPE)*

(A) Limits for Occupational/Controlled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-3.0	614	1.63	(100)*	6
3.0-30	1842/f	4.89/f	($900/f^2$)*	6
30-300	61.4	0.163	1.0	6
300-1500	--	--	f/300	6
1500-100,000	--	--	5	6

(B) Limits for General Population/Uncontrolled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	($180/f^2$)*	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100,000	--	--	1.0	30

f = frequency in MHz *Plane-wave equivalent power density

NOTE 1: Occupational/controlled limits apply in situations in which persons are exposed as a consequence of their employment provided those persons are fully aware of the potential for exposure and can exercise control over their exposure. Limits for occupational/controlled exposure also apply in situations when an individual is transient through a location where occupational/controlled limits apply provided he or she is made aware of the potential for exposure.

NOTE 2: General population/uncontrolled exposures apply in situations in which the general public may be exposed, or in which persons that are exposed as a consequence of their employment may not be fully aware of the potential for exposure or can not exercise control over their exposure.

Table 2. ***FCC Limits for Localized (Partial-body) Exposure***

Specific Absorption Rate (SAR)	
Occupational/Controlled Exposure (100 kHz - 6 GHz)	**General Uncontrolled/Exposure (100 kHz - 6 GHz)**
< 0.4 W/kg whole-body **$\leq$ 8 W/kg partial-body**	**< 0.08 W/kg whole-body** **$\leq$ 1.6 W/kg partial-body**

WHY HAS THE FCC ADOPTED GUIDELINES FOR RF EXPOSURE?

The FCC authorizes and licenses devices, transmitters and facilities that generate RF and microwave radiation. It has jurisdiction over all transmitting services in the U.S. except those specifically operated by the Federal Government. However, the FCC's primary jurisdiction does not lie in the health and safety area, and it must rely on other agencies and organizations for guidance in these matters.

Under the National Environmental Policy Act of 1969 (NEPA), the FCC has certain responsibilities to consider whether its actions will "significantly affect the quality of the human environment." Therefore, FCC approval and licensing of transmitters and facilities must be evaluated for significant impact on the environment. Human exposure to RF radiation emitted by FCC-regulated transmitters is one of several factors that must be considered in such environmental evaluations.

Major RF transmitting facilities under the jurisdiction of the FCC, such as radio and television broadcast stations, satellite-earth stations, experimental radio stations and certain cellular, PCS and paging facilities are required to undergo routine evaluation for RF compliance whenever an application is submitted to the FCC for construction or modification of a transmitting facility or renewal of a license. Failure to comply with the FCC's RF exposure guidelines could lead to the preparation of a formal Environmental Assessment, possible Environmental Impact Statement and eventual rejection of an application. Technical guidelines for evaluating compliance with the FCC RF safety requirements can be found in the FCC's OET Bulletin 65 (Reference 57).

Low-powered, intermittent, or inaccessible RF transmitters and facilities are normally "categorically excluded" from the requirement for ***routine*** evaluation for RF exposure. These exclusions are based on calculations and measurement data indicating that such transmitting stations or devices are unlikely to cause exposures in excess of the guidelines under normal conditions of use.[13] The FCC's policies on RF exposure and categorical exclusion can be found in Section 1.1307(b) of the FCC's Rules and Regulations.[14] It should be emphasized, however, that these exclusions are ***not*** exclusions from compliance, but, rather, only exclusions from routine evaluation. Furthermore, transmitters or facilities that are otherwise categorically excluded from evaluation may be required, on a case-by-case basis, to demonstrate compliance when evidence of potential non-compliance of the transmitter or facility is brought to the Commission's attention [*see* 47 CFR §1.1307(c) and (d)].

The FCC's policies with respect to environmental RF fields are designed to ensure that FCC-regulated transmitters do not expose the public or workers to levels of RF radiation that are considered by expert organizations to be potentially harmful. Therefore, if a transmitter and its associated antenna are regulated by the FCC, they must comply with provisions of the FCC's rules regarding human exposure to RF radiation. In its 1997 Order, the FCC adopted a provision that all transmitters regulated by the FCC, regardless of whether they are excluded from routine evaluation, are expected to be in compliance with the new guidelines on RF exposure by September 1, 2000 (Reference 56).

In the United States some local and state jurisdictions have also enacted rules and regulations pertaining to human exposure to RF energy. However, the Telecommunications Act of 1996 contained provisions relating to federal jurisdiction to regulate human exposure to RF emissions from certain transmitting devices.. In particular, Section 704 of the Act states that, "No State or local government or instrumentality thereof may regulate the placement, construction, and modification of personal wireless service facilities on the basis of the environmental effects of radio frequency emissions to the extent that such facilities comply with the Commission's regulations concerning such emissions." Further information on FCC policy with respect to facilities siting is available in a factsheet from the FCC's Wireless Telecommunications Bureau.[15]

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[13] The Council on Environmental Quality, which has oversight responsibility with regard to NEPA, permits federal agencies to categorically exclude certain actions from routine environmental processing when the potential for individual or cumulative environmental impact is judged to be negligible (40 CFR §§ 1507, 1508.4 and "Regulations for Implementing the Procedural Provisions of NEPA, 43 Fed. Reg. 55,978, 1978).

[14] 47 Code of Federal Regulations 1.1307(b).

[15] "Fact Sheet 2", September 17, 1997, entitled, "*National Wireless Facilities Siting Policies,*" from the FCC's Wireless Telecommunications Bureau. This factsheet can be viewed and downloaded from the bureau's Internet World Wide Web Site: http://www.fcc.gov/wtb/.

ARE EMISSIONS FROM RADIO AND TELEVISION ANTENNAS SAFE?

Radio and television broadcast stations transmit their signals via RF electromagnetic waves. There are currently approximately 14,000 radio and TV stations on the air in the United States. Broadcast stations transmit at various RF frequencies, depending on the channel, ranging from about 550 kHz for AM radio up to about 800 MHz for some UHF television stations. Frequencies for FM radio and VHF television lie in between these two extremes. Operating powers ("effective radiated power") can be as little as a few hundred watts for some radio stations or up to millions of watts for certain television stations. Some of these signals can be a significant source of RF energy in the local environment, and the FCC requires that broadcast stations submit evidence of compliance with FCC RF guidelines.

The amount of RF energy to which the public or workers might be exposed as a result of broadcast antennas depends on several factors, including the type of station, design characteristics of the antenna being used, power transmitted to the antenna, height of the antenna and distance from the antenna. Since energy at some frequencies is absorbed by the human body more readily than energy at other frequencies, the frequency of the transmitted signal as well as its intensity is important. Calculations can be performed to predict what field intensity levels would exist at various distances from an antenna.

Public access to broadcasting antennas is normally restricted so that individuals cannot be exposed to high-level fields that might exist near antennas. Measurements made by the FCC, EPA and others have shown that ambient RF radiation levels in inhabited areas near broadcasting facilities are typically well below the exposure levels recommended by current standards and guidelines (References 32, 46, 48, 51, 52). There have been a few situations around the country where RF levels in publicly accessible areas have been found to be higher than those recommended by applicable safety standards (e.g., see Reference 50). But, in spite of the relatively high operating powers of many stations, such cases are unusual, and members of the general public are unlikely to be exposed to RF levels from broadcast towers that exceed FCC limits. Wherever such situations have arisen corrective measures have been undertaken to ensure that areas promptly come into compliance with the applicable guidelines.

In cases where exposure levels might pose a problem, there are various steps a broadcast station can take to ensure compliance with safety standards. For example, high-intensity areas could be posted and access to them could be restricted by fencing or other appropriate means. In some cases more drastic measures might have to be considered, such as re-designing an antenna, reducing power, or station relocation.

Antenna maintenance workers are occasionally required to climb antenna structures for such purposes as painting, repairs, or beacon replacement. Both the EPA and OSHA have reported that in these cases it is possible for a worker to be exposed to high levels of RF energy if work is performed on an active tower or in areas immediately surrounding a radiating antenna (e.g., see Reference 42, 43, 45, and 51). Therefore, precautions should be taken to ensure that maintenance personnel are not exposed to unsafe RF fields. Such precautions could include temporarily lowering power levels while work is being performed, having work performed only when the station is not broadcasting, using auxiliary antennas while work is performed on the main antenna, and establishing work procedures that would specify the minimum distance that a worker should maintain from an energized antenna.

HOW SAFE ARE MICROWAVE AND SATELLITE ANTENNAS?

Point-to-Point Microwave Antennas

Point-to-point microwave antennas transmit and receive microwave signals across relatively short distances (from a few tenths of a mile to 30 miles or more). These antennas are usually rectangular or circular in shape and are normally found mounted on a supporting tower, on rooftops, sides of buildings or on similar structures that provide clear and unobstructed line-of-sight paths between both ends of a transmission path or link. These antennas have a variety of uses such as transmitting voice and data messages and serving as links between broadcast or cable-TV studios and transmitting antennas.

The RF signals from these antennas travel in a directed beam from a transmitting antenna to a receiving antenna, and dispersion of microwave energy outside of the relatively narrow beam is minimal or insignificant. In addition, these antennas transmit using very low power levels, usually on the order of a few watts or less. Measurements have shown that ground-level power densities due to microwave directional antennas are normally a thousand times or more below recommended safety limits. (e.g., *see* Reference 38) Moreover, as an added margin of safety, microwave tower sites are normally inaccessible to the general public. Significant exposures from these antennas could only occur in the unlikely event that an individual were to stand directly in front of and very close to an antenna for a period of time.

Satellite-Earth Stations

Ground-based antennas used for satellite-earth communications typically are parabolic "dish" antennas, some as large as 10 to 30 meters in diameter, that are used to transmit ("uplinks") or receive ("downlinks") microwave signals to or from satellites in orbit around the earth. The satellites receive the signals beamed up to them and, in turn, retransmit the signals back down to an earthbound receiving station. These signals allow delivery of a variety of communications services, including long distance telephone service. Some satellite-earth station antennas are used only to ***receive*** RF signals (i.e., just like a rooftop television antenna used at a residence), and, since they do not transmit, RF exposure is not an issue.

Since satellite-earth station antennas are directed toward satellites above the earth, transmitted beams point skyward at various angles of inclination, depending on the particular satellite being used. Because of the longer distances involved, power levels used to transmit these signals are relatively large when compared, for example, to those used by the microwave point-to-point antennas discussed above. However, as with microwave antennas, the beams used for transmitting earth-to-satellite signals are concentrated and highly directional, similar to the beam from a flashlight. In addition, public access would normally be restricted at station sites where exposure levels could approach or exceed safe limits.

Although many satellite-earth stations are "fixed" sites, portable uplink antennas are also used, e.g., for electronic news gathering. These antennas can be deployed in various locations. Therefore, precautions may be necessary, such as temporarily restricting access in the vicinity of the antenna, to avoid exposure to the main transmitted beam. In general, however, it is unlikely that a transmitting earth station antenna would routinely expose members of the public to potentially harmful levels of microwaves.

ARE CELLULAR AND PCS TOWERS AND ANTENNAS SAFE? WHAT ABOUT CAR PHONES AND HAND-HELD PHONES?

Base Stations

Cellular radio systems use frequencies between 800 and 900 megahertz (MHz). Transmitters in the Personal Communications Service (PCS) use frequencies in the range of 1850-1990 MHz. The antennas for cellular and PCS transmissions are typically located on towers, water tanks or other elevated structures including rooftops and the sides of buildings. The combination of antennas and associated electronic equipment is referred to as a cellular or PCS "base station" or "cell site." Typical heights for free-standing base station towers or structures are 50-200 feet. A cellular base station may utilize several "omni-directional" antennas that look like poles, 10 to 15 feet in length, although these types of antennas are becoming less common in urban areas.

In urban and suburban areas, cellular and PCS service providers now more commonly use "sector" antennas for their base stations. These antennas are rectangular panels, e.g., about 1 by 4 feet in dimension, typically mounted on a rooftop or other structure, but they are also mounted on towers or poles. The antennas are usually arranged in three groups of three each. One antenna in each group is used to transmit signals to mobile units (car phones or hand-held phones), and the other two antennas in each group are used to receive signals from mobile units.

The FCC authorizes cellular and PCS carriers in various service areas around the country. At a cell site, the total RF power that could be transmitted from each transmitting antenna at a cell site depends on the number of radio channels (transmitters) that have been authorized and the power of each transmitter. Typically, for a cellular base station, a maximum of 21 channels per sector (depending on the system) could be used. Thus, for a typical cell site utilizing sector antennas, each of the three transmitting antennas could be connected to up to 21 transmitters for a total of 63 transmitters per site. When omni-directional antennas are used, up to 96 transmitters could be implemented at a cell site, but this would be unusual. While a typical base station could have as many as 63 transmitters, not all of the transmitters would be expected to operate simultaneously thus reducing overall emission levels. For the case of PCS base stations, fewer transmitters are normally required due to the relatively greater number of base stations.

Although the FCC permits an ***effective radiated power*** (ERP) of up to 500 watts per channel (depending on the tower height), the majority of cellular base stations in urban and suburban areas operate at an ERP of 100 watts per channel or less. An ERP of 100 watts corresponds to an ***actual*** radiated power of about 5-10 watts, depending on the type of antenna used (ERP is not equivalent to the power that is radiated but, rather, is a quantity that takes into consideration transmitter power and antenna directivity). As the capacity of a system is expanded by dividing cells, i.e., adding additional base stations, lower ERPs are normally used. In urban areas, an ERP of 10 watts per channel (corresponding to a radiated power of 0.5 - 1 watt) or less is commonly used. For PCS base stations, even lower radiated power levels are normally used.

The signal from a cellular or PCS base station antenna is essentially directed toward the horizon in a relatively narrow pattern in the vertical plane. The radiation pattern for an omni-directional antenna might be compared to a thin doughnut or pancake centered around the antenna while the pattern for a sector antenna is fan-shaped, like a wedge cut from a pie. As with all forms of electromagnetic energy, the power density from a cellular or PCS transmitter decreases rapidly (according to an inverse square law) as one moves away from the antenna. Consequently, normal ground-level exposure is much less than exposures that might be encountered if one were very close to the antenna and in its main transmitted beam.

Measurements made near typical cellular and PCS installations, especially those with tower-mounted antennas, have shown that ground-level power densities are well below limits recommended by RF/microwave safety standards (References 32, 37, and 45). For example, for a base-station transmitting frequency of 869 MHz the FCC's RF exposure guidelines recommend a Maximum Permissible Exposure level for the public ("general population/uncontrolled" exposure) of about 580 microwatts per square centimeter ($\mu W/cm^2$). This limit is many times greater than RF levels found near the base of typical cellular towers or in the vicinity of lower-powered cellular base station transmitters, such as might be mounted on rooftops or sides of buildings. Measurement data obtained from various sources have consistently indicated that "worst-case" ground-level power densities near typical cellular towers are on the order of 1 $\mu W/cm^2$ or less (usually significantly less). Calculations corresponding to a "worst-case" situation (all transmitters operating simultaneously and continuously at the maximum licensed power) show that in order to be exposed to levels near the FCC's limits for cellular frequencies, an individual would essentially have to remain in the main transmitting beam (at the height of the antenna) and within a few feet from the antenna. This makes it extremely unlikely that a member of the general public could be exposed to RF levels in excess of these guidelines due to cellular base station transmitters. For PCS base station transmitters, the same type of analysis holds, except that at the PCS transmitting frequencies (1850-1990 MHz) the FCC's exposure limits for the public are 1000 $\mu W/cm^2$. Therefore, there would typically be an even greater safety margin between actual public exposure levels and recognized safety limits.

When cellular and PCS antennas are mounted at rooftop locations it is possible that ambient RF levels greater than 1 $\mu W/cm^2$ could be present on the rooftop itself. However, exposures approaching or exceeding the safety guidelines are only likely to be encountered very close to or directly in front of the antennas. For sector-type antennas RF levels to the side and in back of these antennas are insignificant.

Even if RF levels were higher than desirable on a rooftop, appropriate restrictions could be placed on access. Factoring in the time-averaging aspects of safety standards could also be used to reduce potential exposure of workers who might have to access a rooftop for maintenance tasks or other reasons. The fact that rooftop cellular and PCS antennas usually operate at lower power levels than antennas on free-standing towers makes excessive exposure conditions on rooftops unlikely. In addition, the significant signal attenuation of a building's roof minimizes any chance for persons living or working within the building itself to be exposed to RF levels that could approach or exceed applicable safety limits.

Vehicle-Mounted Antennas

Vehicle-mounted antennas used for cellular communications normally operate at a power level of 3 watts or less. These cellular antennas are typically mounted on the roof, on the trunk, or on the rear window of a car or truck. Studies have shown that in order to be exposed to RF levels that approach the safety guidelines it would be necessary to remain very close to a vehicle-mounted cellular antenna for an extended period of time (Reference 20).

Studies have also indicated that exposure of vehicle occupants is reduced by the shielding effect of a vehicle's metal body. Some manufacturers of cellular systems have noted that proper installation of a vehicle-mounted antenna is an effective way to maximize this shielding effect and have recommended antenna installation either in the center of the roof or the center of the trunk. With respect to rear-window-mounted cellular antennas, a minimum separation distance of 30-60 cm (1 to 2 feet) has been suggested to minimize exposure to vehicle occupants that could result from antenna mismatch.

Therefore, properly installed, vehicle-mounted, personal wireless transceivers using up to 3 watts of power result in maximum exposure levels in or near the vehicle that are well below the FCC's safety limits. This assumes that the transmitting antenna is at least 15 cm (about 6 inches) or more from vehicle occupants. Time-averaging of exposure (as appropriate) should result in even lower values when compared with safety guidelines.

Mobile and Portable Phones and Devices

The FCC's exposure guidelines, and the ANSI/IEEE and NCRP guidelines upon which they are based, specify limits for human exposure to RF emissions from hand-held RF devices in terms of *specific absorption rate (SAR).* For exposure of the general public, e.g., exposure of the user of a cellular or PCS phone, the FCC limits RF absorption (in terms of SAR) to 1.6 watts/kg (W/kg), as averaged over one gram of tissue. Less restrictive limits, e.g., 2 W/kg averaged over 10 grams of tissue, are specified by guidelines used in some other countries (Reference 25).

Measurements and computational analysis of SAR in models of the human head and other studies of SAR distribution using hand-held cellular and PCS phones have shown that the 1.6 W/kg limit is unlikely to be exceeded under normal conditions of use (References 4, 16, 27). The same can be said for cordless telephones used in the home. Lower frequency (46-49 MHz) cordless telephones operate at very low power levels that could not result in exposure levels that even come close to the 1.6 W/kg level. Higher frequency cordless phones operating near 900 MHz (near the frequencies used for cellular telephones) operate with power levels similar to or less than those used for cell phones. They are also unlikely to exceed the SAR limits specified by the FCC under normal conditions of use.

In any case, compliance with the 1.6 W/kg safety limit must be demonstrated before FCC approval can be granted for marketing of a cellular or PCS phone. Testing of hand-held phones is normally done under conditions of maximum power usage. However, normal power usage is less since it depends on distance of the user from the base station transmitter. Therefore, typical exposure to a user would actually be expected to be less than that indicated by testing for compliance with the limit.

In recent years, publicity, speculation, and concern over claims of possible health effects due to RF emissions from hand-held wireless telephones prompted industry-sponsored groups to initiate research programs to investigate whether there is any risk to users of these devices. Organizations such as Wireless Technology Research (funded by the cellular radio service industry) and wireless equipment manufacturers, such as Motorola, Inc., have been investigating potential health effects from the use of hand-held cellular telephones and other wireless telecommunications devices.

In 1994, the U.S. General Accounting Office (GAO) issued a report that addressed the status of research on the safety of cellular telephones and encouraged U.S. Government agencies to work closely with industry to address wireless safety issues (Reference 59). In that regard, the Federal Government has been monitoring the results of ongoing research through an inter-agency working group led by the EPA and the FDA's Center for Devices and

Radiological Health. In a 1993 "Talk Paper," the FDA stated that it did not have enough information at that time to rule out the possibility of risk, but if such a risk exists, "it is probably small" (Reference 58). The FDA concluded that there is no proof that cellular telephones can be harmful, but if individuals remain concerned several precautionary actions could be taken, including limiting conversations on hand-held cellular telephones and making greater use of telephones with vehicle-mounted antennas where there is a greater separation distance between the user and the radiating antennas.

HOW SAFE ARE FIXED AND MOBILE RADIO TRANSMITTERS USED FOR PAGING AND "TWO-WAY" COMMUNICATIONS?

"Land-mobile" communications include a variety of communications systems which require the use of portable and mobile RF transmitting sources. These systems operate in narrow frequency bands between about 30 and 1000 MHz. Radio systems used by the police and fire departments, radio paging services and business radio are a few examples of these communications systems. They have the advantage of providing communications links between various fixed and mobile locations.

As with cellular and PCS communications, there are three types of RF transmitters associated with land-mobile systems: base-station transmitters, vehicle-mounted transmitters, and hand-held transmitters. The antennas used for these various transmitters are adapted for their specific purpose. For example, a base-station antenna must radiate its signal to a relatively large area, and, therefore, its transmitter generally has to use much higher power levels than a vehicle-mounted or hand-held radio transmitter.

Although these base-station antennas usually operate with higher power levels than other types of land-mobile antennas, they are normally inaccessible to the public since they must be mounted at significant heights above ground to provide for adequate signal coverage. Also, many of these antennas transmit only intermittently. For these reasons, such base-station antennas have generally not been of concern with regard to possible hazardous exposure of the public to RF radiation. However, studies at rooftop locations have indicated that high-powered paging antennas may increase the potential for exposure to workers or others with access to such sites, e.g., maintenance personnel (Reference 12). This could be a concern especially when multiple transmitters are present. In such cases, restriction of access or other corrective actions may be necessary.[16]

Transmitting power levels for vehicle-mounted land-mobile antennas are generally less than those used by base-station antennas but higher than those used for hand-held units. As with cellular transmitters, some manufacturers recommend that users and other nearby

[16] Methods and techniques for controlling exposure are discussed in OET Bulletin 65 (Reference 57).

individuals maintain a minimum distance (e.g., 1 to 2 feet) from a vehicle-mounted antenna during transmission or mount the antenna in such a way as to provide maximum shielding for vehicle occupants. Studies have shown that this is probably a conservative precaution, particularly when the "duty factor" (percentage of time an antenna is actually radiating) is taken into account since safety standards are "time-averaged." Unlike cellular telephones, which transmit continuously throughout a call, two-way radios normally transmit only when the "press-to-talk" button is depressed. The extent of any possible exposure would also depend on the actual power level and frequency used by the vehicle-mounted antenna. In general, there is no evidence that there would be a safety hazard associated with exposure from vehicle-mounted, two-way antennas when the manufacturer's recommendations are followed.

Hand-held "two-way" portable radios such as walkie-talkies are low-powered devices used to transmit and receive messages over relatively short distances. Because of the relatively low power levels used (usually no more than a few watts) and, especially, because of the intermittency of transmissions (low duty factor) these radios would normally not be considered to cause hazardous exposures to users. As with vehicle-mounted mobile units, time averaging of exposure can normally be considered when evaluating two-way radios for compliance with safety limits, since these units are "push to talk.". Laboratory measurements have been made using hand-held radios operating at various frequencies to determine the amount of RF energy that might be absorbed in the head of a user. In general, the only real possibility of a potential hazard would occur in the unlikely event that the tip of the transmitting antenna were to be placed directly at the surface of the eye, contrary to manufacturers' recommended precautions, or if for some reason continuous exposure were possible over a significant period of time, which is unlikely. If hand-held radios are used properly there is no evidence that they could cause hazardous exposure to RF energy (References 5, 11, 13, and 27).

ARE RF EMISSIONS FROM AMATEUR RADIO STATIONS HARMFUL?

There are hundreds of thousands of amateur radio operators ("hams") worldwide. Amateur radio operators in the United States are licensed by the FCC. The Amateur Radio Service provides its members with the opportunity to communicate with persons all over the world and to provide valuable public service functions, such as making communications services available during disasters and emergencies. Like all FCC licensees, amateur radio operators are expected to comply with the FCC's guidelines for safe human exposure to RF fields. Under the FCC's rules, amateur operators can transmit with power levels of up to 1500 watts. However, most hams use considerably less power than this. Studies by the FCC and others have shown that most amateur radio transmitters would not normally expose persons to RF levels in excess of safety limits. This is primarily due to the relatively low operating powers used by most amateurs, the intermittent transmission characteristics typically used and the relative inaccessibility of most amateur antennas. As long as appropriate distances are maintained from amateur antennas, exposure of nearby persons should be well below safety limits. This has been demonstrated by studies carried out by the FCC and others (Reference 54). If there were any opportunity for significant RF exposure, it would most likely apply to the amateur operator and his or her immediate household. To help ensure compliance of amateur radio facilities with RF exposure guidelines, both the FCC and American Radio Relay League (ARRL) have developed technical publications to assist operators in evaluating compliance of their stations (References 23 and 57).

CAN IMPLANTED ELECTRONIC CARDIAC PACEMAKERS BE AFFECTED BY NEARBY RF DEVICES SUCH AS MICROWAVE OVENS OR CELLULAR TELEPHONES?

Over the past several years there has been concern that signals from some RF devices could interfere with the operation of implanted electronic pacemakers and other medical devices. Because pacemakers are electronic devices, they could be susceptible to electromagnetic signals that could cause them to malfunction. Some allegations of such effects in the past involved emissions from microwave ovens. However, it has never been shown that signals from a microwave oven are strong enough to cause such interference.

The FDA requires pacemaker manufacturers to test their devices for susceptibility to electromagnetic interference (EMI) over a wide range of frequencies and to submit the results as a prerequisite for market approval. Electromagnetic shielding has been incorporated into the design of modern pacemakers to prevent RF signals from interfering with the electronic circuitry in the pacemaker. The potential for the "leads" of pacemakers to be susceptible to RF radiation has also been of some concern, but this does not appear to be a serious problem.

Recently there have been reports of possible interference to implanted cardiac pacemakers from digital RF devices such as cellular telephones. An industry-funded organization, Wireless Technology Research, LLC (WTR), working with the FDA, sponsored an investigation as to whether such interference could occur, and, if so, what corrective actions could be taken. The results of this study were published in 1997 (*see* Reference 24), and WTR and the FDA have made several recommendations to help ensure the safe use of wireless devices by patients with implanted pacemakers. One of the primary recommendations is that digital wireless phones be kept at least six inches from the pacemaker and that they not be placed directly over the pacemaker, such as in the breast pocket, when in the "on" position. Patients with pacemakers should consult their physician or the FDA if they believe that they may have a problem related to RF interference.

WHICH OTHER FEDERAL AGENCIES HAVE RESPONSIBILITIES RELATED TO POTENTIAL RF HEALTH EFFECTS?

Various agencies in the Federal Government have been involved in monitoring, researching or regulating issues related to human exposure to RF radiation. These agencies include the Food and Drug Administration (FDA), the Environmental Protection Agency (EPA), the Occupational Safety and Health Administration (OSHA), the National Institute for Occupational Safety and Health (NIOSH), the National Telecommunications and Information Administration (NTIA) and the Department of Defense (DOD).

By authority of the Radiation Control for Health and Safety Act of 1968, the Center for Devices and Radiological Health (CDRH) of the FDA develops performance standards for the emission of radiation from electronic products including X-ray equipment, other medical devices, television sets, microwave ovens, laser products and sunlamps. The CDRH established a product performance standard for microwave ovens in 1971 limiting the amount of RF leakage from ovens. However, the CDRH has not adopted performance standards for other RF-emitting products. The FDA is, however, the lead federal health agency in monitoring the latest research developments and advising other agencies with respect to the safety of RF-emitting products used by the public, such as cellular and PCS phones.

The FDA's microwave oven standard is an ***emission*** standard (as opposed to an ***exposure*** standard) that allows leakage (measured at five centimeters from the oven surface) of 1 mW/cm^2 at the time of manufacture and a maximum level of 5 mW/cm^2 during the lifetime of the oven.[17] The standard also requires ovens to have two independent interlock systems that prevent the oven from generating microwaves the moment that the latch is released or the door of the oven is opened. The FDA has stated that ovens that meet its standards and are used according to the manufacturer's recommendations are safe for consumer and industrial use.

The EPA has, in the past, considered developing federal guidelines for public exposure to RF radiation. However, EPA activities related to RF safety and health are presently limited to advisory functions. For example, the EPA now chairs an Inter-agency Radiofrequency Working Group, which coordinates RF health-related activities among the various federal agencies with health or regulatory responsibilities in this area.

OSHA is responsible for protecting workers from exposure to hazardous chemical and physical agents. In 1971, OSHA issued a protection guide for exposure of workers to RF radiation [29 CFR 1910.97]. The guide, covering frequencies from 10 MHz to 100 GHz, stated that exposure of workers should not exceed a power density of ten milliwatts per square centimeter (10 mW/cm^2) as averaged over any 6-minute period of the workday. However, this guide was later ruled to be only advisory and not mandatory. Moreover, it was

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[17] 21 Code of Federal Regulations 1030.10.

based on an earlier (1966) American National Standards Institute (ANSI) RF protection guide that has been superseded by revised versions in 1974, 1982 and 1992 (see previous discussion of standards). OSHA personnel have recently stated that OSHA uses the ANSI/IEEE 1992 guidelines for enforcement purposes under OSHA's "general duty clause" (see OSHA's Internet Web Site, listed in Table 3, for further information).

NIOSH is part of the U.S. Department of Health and Human Services. It conducts research and investigations into issues related to occupational exposure to chemical and physical agents. NIOSH has, in the past, undertaken to develop RF exposure guidelines for workers, but final guidelines were never adopted by the agency. NIOSH conducts safety-related RF studies through its Physical Agents Effects Branch.

The NTIA is an agency of the U.S. Department of Commerce and is responsible for authorizing Federal Government use of the RF electromagnetic spectrum. Like the FCC, the NTIA also has NEPA responsibilities and has considered adopting guidelines for evaluating RF exposure from U.S. Government transmitters such as radar and military facilities.

The Department of Defense (DOD) has conducted research on the biological effects of RF energy for a number of years. This research is now conducted primarily at the DOD facility at Brooks Air Force Base, Texas. In addition, the DOD uses the ANSI/IEEE 1992 standard as a guide for protecting military personnel from excessive exposure to RF electromagnetic fields.

WHERE CAN I OBTAIN INFORMATION ON RF EXPOSURE AND HEALTH EFFECTS?

Although relatively few offices or agencies within the Federal Government routinely deal with the issue of human exposure to RF fields, it is possible to obtain information and assistance on certain topics from the following federal agencies. Most of these agencies also have Internet Web sites.

FDA: For information about radiation from microwave ovens and other consumer and industrial products contact: Center for Devices and Radiological Health (CDRH), Food and Drug Administration, Rockville, MD 20857.

EPA: The Environmental Protection Agency's Office of Radiation and Indoor Air is responsible for monitoring potential health effects due to public exposure to RF fields. Contact: Environmental Protection Agency, Office of Radiation and Indoor Air, 401 M Street, S.W., Washington, D.C. 20460.

OSHA: The Occupational Safety and Health Administration's (OSHA) Health Response Team (1781 South 300 West, Salt Lake City, Utah 84165) has been involved in studies related to occupational exposure to RF radiation. OSHA also maintains an Internet World

Wide Web site that may be of interest. The URL (case sensitive) is: http://www.osha-slc.gov/SLTC/ (select subject: radiofrequency radiation).

NIOSH: The National Institute for Occupational Safety and Health (NIOSH) monitors RF-related safety issues as they pertain to the workplace. Contact: NIOSH, Physical Agents Effects Branch, Mail Stop C-27, 4676 Columbia Parkway, Cincinnati, Ohio 45226. Toll-free number: 1-800-35-NIOSH (1-800-356-4674).

DOD: Questions regarding Department of Defense activities related to RF safety and its biological research program can be directed to the Radio Frequency Radiation Branch, Air Force Research Laboratory, Brooks Air Force Base, TX 78235.

FCC: Questions regarding potential RF hazards from FCC-regulated transmitters can be directed to the RF Safety Program, Office of Engineering and Technology, Technical Analysis Branch, Federal Communications Commission, 445 Twelfth Street, S.W., Washington, D.C. 20554. The telephone number for inquiries on RF safety issues is: 1-202-418-2464. Calls for routine information can also be directed to the FCC's toll-free number: 1-888-CALL-FCC (225-5322). Another source of information is the FCC's RF Safety Internet Web site (http://www.fcc.gov/oet/rfsafety) where FCC documents and notices can be viewed and downloaded. Questions can also be sent via e-mail to: rfsafety@fcc.gov.

In addition to government agencies, there are other sources of information and possible assistance regarding environmental RF energy. Some states also maintain non-ionizing radiation programs or, at least, some expertise in this field, usually in a department of public health or environmental control. The list of references at the end of this bulletin can be consulted for detailed information on specific topics, and **Table 3** provides a list of some relevant Internet Web sites.

TABLE 3. ***INTERNET WEB SITES FOR FURTHER INFORMATION***

Note: All Internet addresses below preceded by "http://".
Also, some URL's may be case sensitive

American Radio Relay League**: www.arrl.org**

American National Standards Institute: **www.ansi.org**

Bioelectromagnetics Society**: www.bioelectromagnetics.org**

COST 244 (Europe)**: www.radio.fer.hr/cost244**

DOD: **www.brooks.af.mil/AFRL (***select radiofrequency radiation)*

European Bioelectromagnetics Association: **www.ebea.org**

Electromagnetic Energy Association**: www.elecenergy.com**

Federal Communications Commission: **www.fcc.gov/oet/rfsafety**

ICNIRP (Europe)**: www.icnirp.de**

IEEE: **www.ieee.org**

IEEE Committee on Man & Radiation: **www.seas.upenn.edu/~kfoster/comar.htm**

International Microwave Power Institute: **www.impi.org**

Microwave News: **www.microwavenews.com**

J.Moulder, Med.Coll.of Wisc.**: www.mcw.edu/gcrc/cop/cell-phone-health-FAQ/toc.html**

National Council on Radiation Protection & Measurements: **www.ncrp.com**

NJ Dept Radiation Protection: **www.state.nj.us/dep/rpp (***select non-ionizing radiation)* ***Richard Tell Associates*****: www.radhaz.com**

US OSHA**: www.osha-slc.gov/SLTC** *(select subject: radiofrequency radiation)*

Wireless Industry (CTIA): **www.wow-com.com**

Wireless Industry (PCIA): **www.pcia.com**

World Health Organization EMF Project**: www.who.ch/peh-emf**

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