Please scroll down to see RF Safety Material.

28.3 RF Safety

Amateur Radio is basically a safe activity. In recent years, however, there has been considerable discussion and concern about the possible hazards of electromagnetic fields (EMF), including both RF energy and power frequency (50-60 Hz) EMF. FCC regulations set limits on the maximum permissible exposure (MPE) allowed from the operation of radio transmitters. Following these regulations, along with the use of good RF practices, will make your station as safe as possible. This section, written by the ARRL RF Safety Committee (see sidebar), deals with the topic of electromagnetic safety.

28.3.1 How EMF Affects Mammalian Tissue

All life on Earth has adapted to live in an environment of weak, natural, low frequency electromagnetic fields, in addition to the Earth's static geomagnetic field. Natural low-frequency EM fields come from two main sources: the sun and thunderstorm activity. During the past 100 years, man-made fields at much higher intensities and with different spectral distributions have altered our EM background. Researchers continue to look at the effects of RF exposure over a wide range of frequencies and levels.

Both RF and power frequency fields are classified as *nonionizing radiation* because the frequency is too low for there to be enough photon energy to ionize atoms. *Ionizing radiation*, such as X-rays, gamma rays and some ultraviolet radiation, has enough energy to knock electrons loose from atoms. When this happens, positive and negative *ions* are formed. Still, at sufficiently high power densities, non-ionizing EMF poses certain health hazards.

It has been known since the early days of radio that RF energy can cause injuries by heating body tissue. Anyone who has ever touched an improperly grounded radio chassis or energized antenna and received an *RF burn* will agree that this type of injury can be quite painful. Excessive RF heating of the male reproductive organs can cause sterility by damaging sperm. Other health problems also can result from RF heating. These heat related health hazards are called *thermal effects*. A microwave oven is an application that puts thermal effects to practical use.

There also have been observations of changes in physiological function in the presence of RF energy levels that are too low to cause heating. These functions generally return to normal when the field is removed. Although research is ongoing, no harmful health consequences have been linked to these changes.

In addition to the ongoing research, much else has been done to address this issue. For example, FCC regulations set limits on exposure from radio transmitters. The Institute of Electrical and Electronics Engineers, the American National Standards Institute and the National Council for Radiation Protection and Measurement, among others, have recommended voluntary guidelines to limit human exposure to RF energy. The ARRL maintains an RF Safety Committee, consist-

The ARRL RF Safety Committee

Imagine you wake up one day and the newspaper headlines are screaming that scientists have discovered radio waves cause cancer. How would you react? How would your neighbor react? You may not have to imagine very hard because the news has been inundated with this type of story regularly over the past couple of decades. Clearly our society has not been decimated by epidemics of diseases since the vast increase in cellular telephone use. Some people deal with this discrepancy by ignoring all scientific reports. Others adopt a pessimistic attitude that technology is going to kill us all eventually, while still others treat every such story as "the truth" and militantly try to stop the transmission of RF energy. The reality is that while all scientific study is complex, the study of electromagnetic biological effects is even more so. Few newspaper reporters are capable of understanding the nuances of a scientific study and are even less able to properly report its results to the lay public. As a result many newspaper stories mislead the public into thinking that a scientific study has found something about which they need to be warned.

The ARRL has dealt with this dilemma by creating the RF Safety Committee, a group of experts in the facets of medical, scientific and engineering investigation needed to fully critique and understand the results of studies on electromagnetic biological effects. Experts in Dosimetry, Public Health, Epidemiology, Statistical Methods, General Medicine and specific diseases are well suited to reading and understanding published scientific reports and critiquing their validity.

It is not uncommon to examine how an experiment was performed only to realize that errors were made in the design of the experiment or the interpretation of its results. It takes a group of reviewers with a wide range of expertise to consider the implications of all aspects of the study to recognize the value of the results.

The field of biological effects of electromagnetic energy constitutes a complex combination of scientific disciplines. Many scientific studies in this field do not generate reliable results because they are not based on input from experts in the many fields that affect the interactions between electromagnetic energy and biological organisms. Even well designed scientific studies are subject to misinterpretation when the results are presented to a public that does not understand or appreciate the complex interactions that occur between the physical world and biological organisms and how these affect public health.

Since the 1960s there have been thousands of scientific studies that were intended to discover if electromagnetic energy had an adverse affect on biological tissue. A large number of these studies, designed and performed by biologists, did not accurately expose the subjects to known levels of electromagnetic energy. A field of expertise in RF engineering, called dosimetry, was developed to accurately determine the exact field strengths of both electrical and magnetic fields to which subjects were exposed. It has been imperative that an expert in electromagnetic dosimetry be involved in study design, though even today this requirement is often ignored. The RF Safety committee contains expertise in dosimetry that often discovers experimental errors in published results due to misstatements of the amount of exposure that subjects experienced.

Epidemiological studies have the potential to recognize disease trends in populations. However, they can also develop misleading results. Epidemiology looks for health trends among people with similar types of exposures as compared to a similar group of people that does not have the same type of exposure. (This type of study has become difficult to perform with cellular telephones because it is hard to find people who do not use them). The great diversity of the population makes it difficult to know that there is not some other exposure that affects the study group. The RF Safety committee contains expertise in epidemiology to make sense of claims based on epidemiological evidence, and the review of the methods and results can reveal a lesser impact of the study than the author or the press had implied.

Some experimental studies correctly demonstrate biological changes due to exposure to electromagnetic fields. A change in a biological tissue that occurs because of the presence of some form of energy may be an interesting finding, but it does not imply that this change will lead to a public health problem. (An obvious example is contraction of the eye pupil in the presence of bright light, a form of electromagnetic energy). The RF Safety Committee contains expertise in Public Health that helps to determine if there may be a correlation between a laboratory finding and any potential concern for the health of people in our society.

The ARRL RF Safety Committee serves as a resource to the ARRL Board of Directors, providing advice that helps them formulate ARRL policy related to RF safety. The RFSC interacts with the ARRL HQ staff to ensure that RF safety is appropriately addressed in ARRL publications and on the ARRL website. The Amateur Radio community corresponds with the RFSC for help with RF safety-related questions and problems. RFSC members monitor and analyze relevant published research. Its members participate in standards coordinating committees and other expert committees related to RF safety. The RFSC is responsible for writing the RF safety text that is included in ARRL publications. The accuracy of RF safety-related issues in articles submitted to *QST* and *QEX* are confirmed by committee members. The RFSC also participates in developing the RF safety questions for FCC amateur question pools and works with the FCC in developing its environmental regulations. Radio amateurs with questions related to RF safety can contact the RFSC via its liaison, Ed Hare, W1RFI, **w1rfi@arrl.org**. The RFSC maintains a webpage at **www.arrl.org/arrl-rf-safety-committee**.

ing of concerned scientists and medical doctors, who volunteer to serve the radio amateur community to monitor scientific research and to recommend safe practices.

THERMAL EFFECTS OF RF ENERGY

Body tissues that are subjected to *very high* levels of RF energy may suffer serious heat damage. These effects depend on the frequency of the energy, the power density of the RF field that strikes the body and factors such as the polarization of the wave and the grounding of the body.

At frequencies near the body's natural resonances RF energy is absorbed more efficiently. In adults, the primary resonance frequency is usually about 35 MHz if the person is grounded, and about 70 MHz if insulated from the ground. Various body parts are resonant at different frequencies. Body size thus determines the frequency at which most RF energy is absorbed. As the frequency is moved farther from resonance, RF energy absorption becomes less efficient. *Specific absorption rate (SAR)* is a measure that takes variables such as resonance into account to describe the rate at which RF energy is absorbed in tissue, typically measured in watts per kilogram of tissue (W/kg).

Maximum permissible exposure (MPE) limits define the maximum electric and magnetic field strengths, and the plane-wave equivalent power densities associated with these fields, that a person may be exposed to without harmful effect, and are based on whole-body SAR safety levels. The safe exposure limits vary with frequency as the efficiency of absorption changes. The MPE limits Safety factors are included to insure that the MPE field strength will never result in an unsafe SAR.

Thermal effects of RF energy are usually not a major concern for most radio amateurs because the power levels normally used tend to be low and the intermittent nature of most amateur transmissions decreases total exposure. Amateurs spend more time listening than transmitting and many amateur transmissions such as CW and SSB use low-duty-cycle modes. With FM or RTTY, though, the RF is present continuously at its maximum level during each transmission. It is rare for radio amateurs to be subjected to RF fields strong enough to produce thermal effects, unless they are close to an energized antenna or unshielded power amplifier. Specific suggestions for avoiding excessive exposure are offered later in this chapter.

ATHERMAL EFFECTS OF EMF

Biological effects resulting from exposure to power levels of RF energy that do not generate measurable heat are called *athermal effects*. A number of athermal effects of EMF exposure on biological tissue have been seen in the laboratory. However, to date all athermal effects that have been discovered have had the same features: They are transitory, or go away when the EMF exposure is removed, and they have not been associated with any negative health effects.

28.3.2 Researching Biological Effects of EMF Exposure

The statistical basis of scientific research that confuses many non-scientists is the inability of science to state unequivocally that EMF is safe. Effects are studied by scientists using statistical inference where the "null hypothesis" assumes there is no effect and then tries to disprove this assumption by proving an "alternative hypothesis" that there is an effect. The alternative hypothesis can never be entirely disproved because a scientist cannot examine every possible case, so scientists only end up with a *probability* that the alternative hypothesis is *not* true. Thus, to be entirely truthful, a scientist can never say that something was proven; with respect to low-level EMF exposure, no scientist can guarantee that it is absolutely safe. At best, science can only state that there is a very low probability that it is unsafe. While scientists accept this truism, many members of the general public who are suspicious of EMF and its effects on humans see this as a reason to continue to be afraid.

There are two types of scientific study that are used to learn about the effects of EMF exposure on mammalian biology: laboratory and epidemiological.

LABORATORY STUDY

Scientists conduct laboratory research using animals to learn about biological mechanisms by which EMF may affect mammals. The main advantage of laboratory studies on the biological effects of EMF is that the exposures can be controlled very accurately.

Some major disadvantages of laboratory study also exist. EMF exposure may not affect the species of animals used in the investigations the same way that humans may respond. A common example of this misdirection occurred with eye research. Rabbits had been used for many years to determine that exposure of the eyes to high levels of EMF could cause cataracts. The extrapolation of these results to humans led to the fear that use of radio would harm one's vision. However, the rabbit's eye is on the surface of its skull while the human eye is buried deep within the bony orbit in the skull. Thus, the human eye receives much less exposure from EMF and is less likely to be damaged by the same exposures that had been used in the laboratory experiments on rabbits.

Some biological processes that affect tissue can take many years to occur and laboratory experiments on animals tend to be of shorter duration, in part because the life spans of most animals are much shorter than that of humans. For instance, a typical laboratory rat can be studied at most for two years, during which it progresses from youth to old age with all of the attendant physiological changes that come from normal aging. A disease process that takes multiple exposures over many years to occur is unlikely to be seen in a laboratory study with small animals.

EPIDEMIOLOGICAL RESEARCH

Epidemiologists look at the health patterns of large groups of people using statistical methods. In contrast to laboratory research, epidemiological research has very poor control of its subjects' exposures to EMF but it has the advantages of being able to analyze the effects of a lifetime of exposure and of being able to average out variations among large populations of subjects. By their basic design, epidemiological studies do not demonstrate cause and effect, nor do they postulate mechanisms of disease. Instead, epidemiologists look for associations between an environmental factor and an observed pattern of illness. Apparent associations are often seen in small preliminary studies that later are shown to have been incorrect. At best, such results are used to motivate more detailed epidemiological studies and laboratory studies that narrow down the search for cause-and-effect.

Some preliminary studies have suggested a weak association between exposure to EMF at home or at work and various malignant conditions including leukemia and brain cancer. A larger number of equally well-designed and performed studies, however, have found no association. Risk ratios as high as 2 have been observed in some studies. This means that the number of observed cases of disease in the test group is up to 2 times the "expected" number in the population. Epidemiologists generally regard a risk ratio of 4 or greater to be indicative of a strong association between the cause and effect under study. For example, men who smoke one pack of cigarettes per day increase their risk for lung cancer tenfold compared to nonsmokers and two packs per day increases the risk to more than 25 times the nonsmokers' risk.

Epidemiological research by itself is rarely conclusive, however. Epidemiology only identifies health patterns in groups — it does not ordinarily determine their cause. There are often confounding factors. Most of us are exposed to many different environmental hazards that may affect our health in various ways. Moreover, not all studies of persons likely to be exposed to high levels of EMF have yielded the same results (see sidebar on preliminary epidemiological studies).

Preliminary Epidemiology

Just about every week you can pick up the newspaper and see a screaming banner headline such as: "Scientists Discover Link Between Radio Waves and Disease." So why are you still operating your ham radio? You've experienced the inconsistency in epidemiological study of diseases. This is something that every radio amateur should understand in order to know how to interpret the real meaning of the science behind the headlines and to help assuage the fears that these stories elicit in others.

Just knowing that someone who uses a radio gets a disease, such as cancer, doesn't tell us anything about the cause-and-effect of that disease. People came down with cancer, and most other diseases, long before radio existed. What epidemiologists try to identify is a group of people who all have a common exposure to something and all suffer from a particular disease in higher proportion than would be expected if they were not exposed. This technique has been highly effective in helping health officials notice excesses of disease due to things such as poisoning of water supplies by local industry and even massive exposures such as smoking. However, epidemiology rarely proves that an exposure causes a disease; rather it provides the evidence that leads to further study.

While the strength of epidemiology is that it helps scientists notice anomalies in entire populations, its weakness is that it is non-specific. An initial epidemiological study examines only two things: suspected exposures and rates of diseases. These studies are relatively simple and inexpensive to perform and may point to an apparent association that then bears further study. For instance, in one study of the causes of death of a selection of Amateur Radio operators, an excess of leukemia was suggested. The percentage of ham radio operators who died of leukemia in that study was higher than expected based on the percentage of the rest of the population that died of leukemia. By itself, this has little meaning and should not be a cause for concern, since the study did not consider anything else about the sample population except that they had ham licenses. Many other questions arise: Were the study subjects exposed to any unusual chemicals? Did any of the study subjects have a family history of leukemia? Did the licensed amateurs even operate radios, what kind and how often? To an epidemiologist, this result might provide enough impetus to raise the funds to gather more specific information about each subject and perform a more complete study that strengthens the apparent associations. However, a slight excess of disease in a preliminary study rarely leads to further study. Commonly, an epidemiologist does not consider a preliminary study to be worth pursuing unless the ratio of excess disease, also called the risk ratio, is 4:1 or greater. Unfortunately, most news reporters are not epidemiologists and do not understand this distinction. Rather, a slight excess of disease in a preliminary study can lead to banner headlines that raise fear in the society, causing unreasonable resistance to things like cell phones and ham radios.

Headlines that blow the results of preliminary epidemiological studies out of proportion are rarely followed by retractions that are as visible if the study is followed up by one that is more complete and shows no association with disease. In the case of the aforementioned epidemiological study of hams' licensing and death records, overblown publicity about the results has led to the urban legend that ham radio operators are likely to come down with leukemia. Not only is this an unfounded conclusion due to the preliminary nature of the original study, but a similar study was recently performed by the National Cancer Institute using a far larger number of subjects and no significant excess of any disease was found. Hams should be able to recognize when sensationalistic headlines are based on inconclusive science and should be prepared to explain to their families, friends and neighbors just how inconclusive such results are.

28.3.3 Safe Exposure Levels

How much EMF energy is safe? Scientists and regulators have devoted a great deal of effort to deciding upon safe RF-exposure limits. This is a very complex problem, involving difficult public health and economic considerations. The recommended safe levels have been revised downward several times over the years — and not all scientific bodies agree on this question even today. The latest Institute of Electrical and Electronics Engineers (IEEE) C95.1 standard for recommended radio frequency exposure limits was published in 2006, updating one that had previously been published in 1991 and adopted by the American National Standards Institute (ANSI) in 1992. In the new standard changes were made to better reflect the current research, especially related to the safety of cellular telephones. At some frequencies the new standard determined that higher levels of exposure than previously thought are safe (see sidebar, "Where Do RF Safety Standards Come From?").

The IEEE C95.1 standard recommends frequency-dependent and time-dependent maximum permissible exposure levels. Unlike earlier versions of the standard, the 1991 and 2006 standards set different RF exposure limits in *controlled environments* (where energy levels can be accurately determined and everyone on the premises is aware of the presence of EM fields) and in *uncontrolled environments* (where energy levels are not known or where people may not be aware of the presence of EM fields). FCC regulations adopted these concepts to include controlled/occupational and uncontrolled/general population exposure limits.

The graph in **Figure 28.22** depicts the 1991 IEEE standard (which is still used as the basis of FCC regulation). It is necessarily a complex graph, because the standards differ not only for controlled and uncontrolled environments but also for electric (E) fields and magnetic (H) fields. Basically, the lowest E-field exposure limits occur at frequencies between 30 and 300 MHz. The lowest H-field exposure levels occur at 100-300 MHz. The ANSI standard sets the maximum E-field limits between 30 and 300 MHz at a power density of 1 mW/cm^2 (61.4 V/m) in controlled environments — but at one-fifth that level (0.2 mW/cm^2 or 27.5 V/m) in uncontrolled environments. The H-field limit drops to 1 mW/cm^2 (0.163 A/m) at 100-300 MHz in controlled environments and 0.2 mW/cm^2 (0.0728 A/m) in uncontrolled environments. Higher power densities are permitted at frequencies below 30 MHz (below 100 MHz for H fields) and above 300 MHz, based on the concept that the body will not be resonant at those frequencies and will therefore absorb less energy.

In general, the ANSI/IEEE standard requires averaging the power level over time periods ranging from 6 to 30 minutes for power-density calculations, depending on the frequency and other variables. The ANSI/IEEE exposure limits for uncontrolled environments are lower than those for controlled environments, but to compensate for that the standard allows exposure levels in those environments to be averaged over much longer time periods (generally 30 minutes). This long averaging time means that an intermittent RF source (such as an Amateur Radio transmitter) will result in a much lower exposure than a continuous-duty station, with all other parameter being equal. Time averaging is based on the concept that the human body can withstand a greater rate of body heating (and thus, a higher level of RF energy) for a short time.

Another national body in the United States, the National Council for Radiation Protection and Measurement (NCRP), also has adopted recommended exposure guidelines. NCRP urges a limit of 0.2 mW/cm^2 for nonoccupational exposure in the 30- 300 MHz range. The NCRP guideline differs from IEEE in that it takes into account the effects of modu-

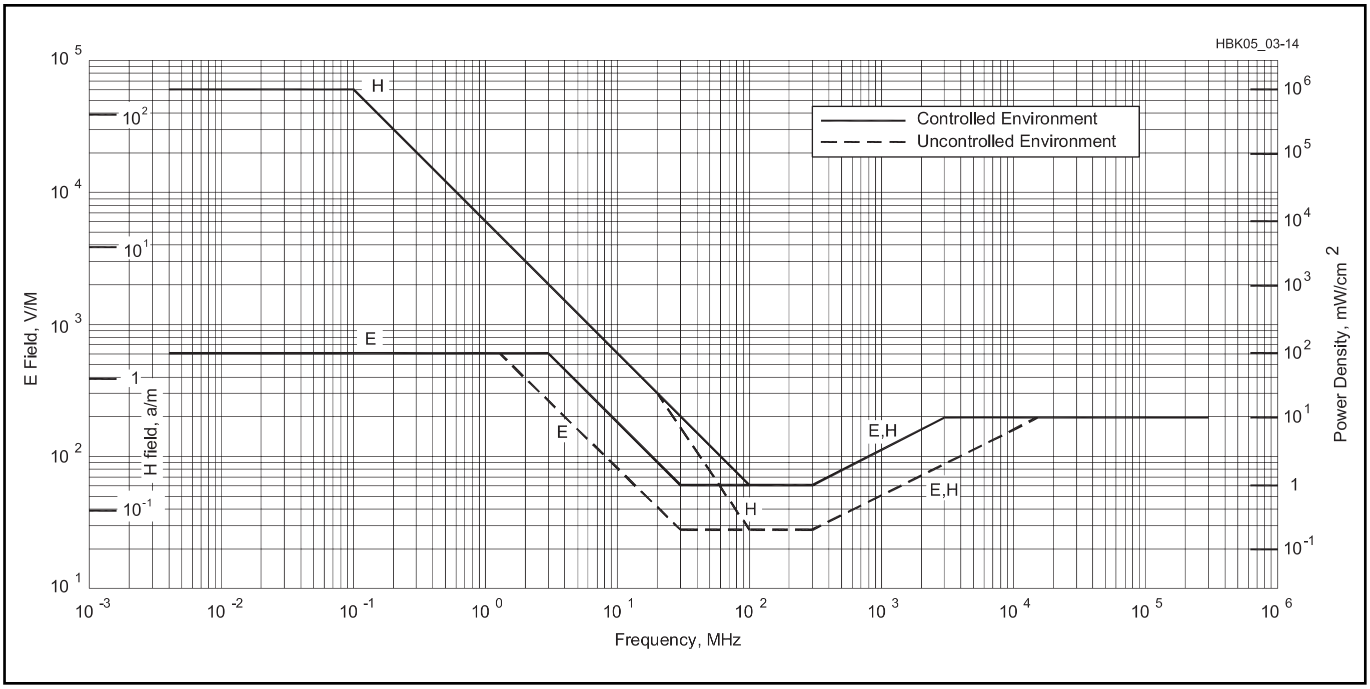

Figure 28.22 — 1991 RF protection guidelines for body exposure of humans. It is known officially as the "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz."

Where Do RF Safety Standards Come From?

So much of the way we deal with RF Safety is based on "Safety Standards." The FCC environmental exposure regulations that every ham must follow are largely restatements of the conclusions reached by some of the major safety standards. How are these standards developed and why should we trust them?

The preeminent RF safety standard in the world was developed by the Institute of Electrical and Electronics Engineers (IEEE). The most recent edition is entitled *C95.1 -2005: IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.* The IEEE C95.1 Standard has a long history. The first C95.1 RF safety standard was released in 1966, was less than 2 pages long and listed no references. It essentially said that for frequencies between 10 MHz and 100 GHz people should not be exposed to a power density greater than 10 mW/cm^2. The C95.1 standard was revised in 1974, 1982, 1991 and 2005. The latest (2005) edition of the standard was published in 2006, is 250 pages long and has 1143 references to the scientific literature. Most of the editions of the IEEE C95.1 standard were adopted by the American National Standards Institute (ANSI) a year or two after they were published by IEEE. The 2005 edition was adopted by ANSI in 2006.

The committee at IEEE that developed the latest revision to C95.1 is called International Committee on Electromagnetic Safety Technical Committee 95 Subcommittee 4 and had a large base of participants. The subcommittee was co-chaired by C-K Chou, Ph.D., of Motorola Laboratories, and John D'Andrea, PhD, of the U.S. Naval Health Research Center. The committee had 132 members, 42% of whom were from 23 countries outside the United States. The members of the committee represented academia (27%), government (34%), industry (17%), consultants (20%) and the general public (2%).

Early editions of C95.1 were based on the concept that heat generated in the body should be limited to prevent damage to tissue. Over time the standard evolved to protect against *all known adverse biological effects* regardless of the amount of heat generated. The 2005 revision was based on the principles that the standard should protect human health yet still be practical to implement, its conclusions should be based solely on scientific evidence and wherever scientifically defensible it should be harmonized with other international RF safety standards. It based its conclusions on 50 years of scientific study. From over 2500 studies on EMF performed during that time, 1300 were selected for their relevance to the health effects of RF exposure. The science in these studies was evaluated for its quality and methodology and 1143 studies were referenced in producing the latest standard.

Other major standards bodies have published similar standards. The National Council for Radiation Protection and Measurement (NCRP) published its safety standard entitled, *Report No. 86: Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields* in 1986. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) published its safety standard entitled *Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (Up to 300 GHz)* in 1998.

FCC RF Exposure Regulations

FCC regulations control the amount of RF exposure that can result from your station's operation (§§97.13, 97.503, 1.1307 (b)(c)(d), 1.1310, 2.1091 and 2.1093). The regulations set limits on the maximum permissible exposure (MPE) allowed from operation of transmitters in all radio services. They also require that certain types of stations be evaluated to determine if they are in compliance with the MPEs specified in the rules. The FCC has also required that questions on RF environmental safety practices be added to Technician and General license examinations.

THE RULES

Maximum Permissible Exposure (MPE)

All radio stations regulated by the FCC must comply with the requirements for MPEs, even QRP stations running only a few watts or less. The MPEs vary with frequency, as shown in **Table A**. MPE limits are specified in maximum electric and magnetic fields for frequencies below 30 MHz, in power density for frequencies above 300 MHz and all three ways for frequencies from 30 to 300 MHz. For compliance purposes, all of these limits must be considered *separately*. If any one is exceeded, the station is not in compliance. In effect, this means that both electric and magnetic field must be determined below 300 MHz but at higher frequencies determining either the electric or magnetic field is normally sufficient.

The regulations control human exposure to RF fields, not the strength of RF fields in any space. There is no limit to how strong a field can be as long as no one is being exposed to it, although FCC regulations require that amateurs use the minimum necessary power at all times (§97.311 [a]).

Table A
(From §1.1310) Limits for Maximum Permissible Exposure (MPE)

(A) Limits for Occupational/Controlled Exposure

Frequency Range (MHz)	*Electric Field Strength (V/m)*	*Magnetic Field Strength (A/m)*	*Power Density (mW/cm²)*	*Averaging Time (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

f = frequency in MHz
* = Plane-wave equivalent power density (see Notes 1 and 2).

(B) Limits for General Population/Uncontrolled Exposure

Frequency Range (MHz)	*Electric Field Strength (V/m)*	*Magnetic Field Strength (A/m)*	*Power Density (mW/cm²)*	*Averaging Time (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 (see Notes 1 and 2).

Note 1: This means the equivalent far-field strength that would have the E or H-field component calculated or measured. It does not apply well in the near field of an antenna. The equivalent far-field power density can be found in the near or far field regions from the relationships: $P_d = |E_{total}|^2 / 3770$ mW/cm² or from $P_d = |H_{total}|^2 \times 37.7$ mW/cm².

Note 2: $|E_{total}|^2 = |E_x|^2 + |E_y|^2 + |E_z|^2$, and $|H_{total}|^2 = |H_x|^2 + |H_y|^2 + |H_z|^2$

Environments

The FCC has defined two tiers of exposure limits — *occupational/controlled limits* and *general population/uncontrolled limits*. Occupational/controlled limits apply when people are exposed as a condition of their employment and when they are aware of that exposure and can take steps to minimize it, if appropriate. General population/uncontrolled limits apply to exposure of the general public or people who are not normally aware of the exposure or cannot exercise control over it. The limits for general population/uncontrolled exposure are more stringent than the limits for occupational/controlled exposure. Specific definitions of the exposure categories can be found in Section 1.1310 of the FCC rules.

Although occupational/controlled limits are usually applicable in a workplace environment, the FCC has determined that they generally apply to amateur operators and members of their immediate households. In most cases, occupational/

lation on an RF carrier.

The FCC MPE regulations are based on a combination of the 1992 ANSI/IEEE standard and 1986 NCRP recommendations. The MPE limits under the regulations are slightly different than the ANSI/IEEE limits and do not reflect all the assumptions and exclusions of the ANSI/IEEE standard.

28.3.4 Cardiac Pacemakers and RF Safety

It is a widely held belief that cardiac pacemakers may be adversely affected in their function by exposure to electromagnetic fields. Amateurs with pacemakers may ask whether their operating might endanger themselves or visitors to their shacks who have a pacemaker. Because of this, and similar concerns regarding other sources of EM fields, pacemaker manufacturers apply design methods that for the most part shield the pacemaker circuitry from even relatively high EM field strengths.

It is recommended that any amateur who has a pacemaker, or is being considered for one, discuss this matter with his or her physician. The physician will probably put the amateur into contact with the technical representative of the pacemaker manufacturer. These representatives are generally excellent resources, and may have data from laboratory or "in the field" studies with specific model pacemakers.

One study examined the function of a modern (dual chamber) pacemaker in and around an Amateur Radio station. The pacemaker generator has circuits that receive and process electrical signals produced by the heart, and also generate electrical signals that stimulate (pace) the heart. In one series of experiments, the pacemaker was connected to a heart simulator. The system was placed on top of the cabinet of a 1-kW HF linear amplifier during SSB and CW operation. In another test, the system was placed in close proximity to several 1 to 5-W 2-meter hand-held transceivers. The test pacemaker was connected to the heart simulator in a third test, and then placed on the ground 9 meters below and 5 meters in front of a three-element Yagi HF antenna. No interference with pacemaker function was controlled limits can be applied to your home and property to which you can control physical access. The general population/uncontrolled limits are intended for areas that are accessible by the general public, such as your neighbors' properties.

The MPE levels are based on average exposure. An averaging time of 6 minutes is used for occupational/controlled exposure; an averaging period of 30 minutes is used for general population/uncontrolled exposure.

Station Evaluations

The FCC requires that certain amateur stations be evaluated for compliance with the MPEs. Although an amateur can have someone else do the evaluation, it is not difficult for hams to evaluate their own stations. The ARRL book *RF Exposure and You* contains extensive information about the regulations and a large chapter of tables that show compliance distances for specific antennas and power levels. Generally, hams will use these tables to evaluate their stations. Some of these tables have been included in the FCC's information — *OET Bulletin 65* and its *Supplement B* (available for downloading at the FCC's RF Safety website). If hams choose, however, they can do more extensive calculations, use a computer to model their antenna and exposure, or make actual measurements.

Categorical Exemptions

Some types of amateur stations do not need to be evaluated, but these stations must still comply with the MPE limits. The station licensee remains responsible for ensuring that the station meets these requirements.

The FCC has exempted these stations from the evaluation requirement because their output power, operating mode and frequency are such that they are presumed to be in compliance with the rules.

Stations using power equal to or less than the levels in **Table B** do not have to be evaluated on a routine basis. For the 100-W HF ham station, for example, an evaluation would be required only on 12 and 10 meters.

Hand-held radios and vehicle-mounted mobile radios that operate using a push-to-talk (PTT) button are also categorically exempt from performing the routine evaluation.

Repeater stations that use less than 500 W ERP or those with antennas not mounted on buildings; if the antenna is at least 10 meters off the ground, also do not need to be evaluated.

Correcting Problems

Most hams are already in compliance with the MPE requirements. Some amateurs, especially those using indoor antennas or high-power, high-duty-cycle modes such as a RTTY bulletin station and specialized stations for moon bounce operations and the like may need to make adjustments to their station or operation to be in compliance.

The FCC permits amateurs considerable flexibility in complying with these regulations. As an example, hams can adjust their operating frequency, mode or power to comply with the MPE limits. They can also adjust their operating habits or control the direction their antenna is pointing.

More Information

This discussion offers only an overview of this topic; additional information can be found in *RF Exposure and You* and on the ARRL website at **www.arrl.org/rf-exposure**. The ARRL website has links to the FCC website, with OET Bulletin 65 and Supplement B and links to software that hams can use to evaluate their stations.

Table B

Power Thresholds for Routine Evaluation of Amateur Radio Stations

Wavelength Band	*Evaluation Required if Power* (watts) Exceeds:*
MF	
160 m	500
HF	
80 m	500
75 m	500
40 m	500
30 m	425
20 m	225
17 m	125
15 m	100
12 m	75
10 m	50
VHF (all bands)	50
UHF	
70 cm	70
33 cm	150
23 cm	200
13 cm	250
SHF (all bands)	250
EHF (all bands)	250
Repeater stations (all bands)	Non-building-mounted antennas: height above ground level to lowest point of antenna < 10 m *and* power > 500 W ERP Building-mounted antennas: power > 500 W ERP

*Transmitter power = Peak-envelope power input to antenna. For repeater stations only, power exclusion based on ERP (effective radiated power).

observed in these experiments.

Although the possibility of interference cannot be entirely ruled out by these few observations, these tests represent more severe exposure to EM fields than would ordinarily be encountered by an amateur — with an average amount of common sense. Of course prudence dictates that amateurs with pacemakers, who use handheld VHF transceivers, keep the antenna as far as possible from the site of the implanted pacemaker generator. They also should use the lowest transmitter output required for adequate communication. For high power HF transmission, the antenna should be as far as possible from the operating position, and all equipment should be properly grounded.

28.3.5 Low-Frequency Fields

There has been considerable laboratory research about the biological effects of power line EMF. For example, some separate studies have indicated that even fairly low levels of EMF exposure might alter the human body's circadian rhythms, affect the manner in which T lymphocytes function in the immune system and alter the nature of the electrical and chemical signals communicated through the cell membrane and between cells, among other things. Although these studies are intriguing, they do not demonstrate any effect of these low-level fields on the overall organism.

Much of this research has focused on low-frequency magnetic fields, or on RF fields that are keyed, pulsed or modulated at a low audio frequency (often below 100 Hz). Several studies suggested that humans and animals could adapt to the presence of a steady RF carrier more readily than to an intermittent, keyed or modulated energy source.

The results of studies in this area, plus speculations concerning the effect of various types of modulation, were and have remained somewhat controversial. None of the research to date has demonstrated that low-level EMF causes adverse health effects.

Given the fact that there is a great deal of ongoing research to examine the health consequences of exposure to EMF, the American Physical Society (a national group of highly respected scientists) issued a statement in May 1995 based on its review of available data pertaining to the possible connections of cancer to 60-Hz EMF exposure. Their report is exhaustive and should be reviewed by anyone with a serious interest in the field. Among its general conclusions are the following:

1. The scientific literature and the reports of reviews by other panels show no consistent, significant link between cancer and power line fields.

2. No plausible biophysical mechanisms for the systematic initiation or promotion of cancer by these extremely weak 60-Hz fields have been identified.

3. While it is impossible to prove that no deleterious health effects occur from exposure to any environmental factor, it is necessary to demonstrate a consistent, significant, and causal relationship before one can conclude that such effects do occur.

In a report dated October 31, 1996, a committee of the National Research Council of the National Academy of Sciences has concluded that no clear, convincing evidence exists to show that residential exposures to electric and magnetic fields (EMF) are a threat to human health.

A National Cancer Institute epidemiological study of residential exposure to magnetic fields and acute lymphoblastic leukemia in children was published in the *New England Journal of Medicine* in July 1997. The exhaustive, seven-year study concludes that if there is any link at all, it is far too weak to be of concern.

In 1998, the US National Institute on Environmental Health Sciences organized a working group of experts to summarize the research on power-line EMF. The committee used the classification rules of the International Agency for Research on Cancer (IARC) and performed a meta-analysis to combine all past results as if they had been performed in a single study. The NIEHS working group concluded that the research did not show this type of exposure to be a carcinogen but could not rule out the possibility either. Therefore, they defined power-line EMF to be a Class 2b carcinogen under the IARC classification. The definition, as stated by the IARC is: "Group 2B: The agent is possibly carcinogenic to humans. There is limited pidemiological evidence plus limited or inadequate animal evidence." Other IARC Class 2b carcinogens include automobile exhaust, chloroform, coffee, ceramic and glass fibers, gasoline and pickled vegetables.

Readers may want to follow this topic as further studies are reported. Amateurs should be aware that exposure to RF and ELF (60 Hz) electromagnetic fields at all power levels and frequencies has not been fully studied under all circumstances. "Prudent avoidance" of any avoidable EMF is always a good idea. Prudent avoidance doesn't mean that amateurs should be fearful of using their equipment. Most amateur operations are well within the MPE limits. If any risk does exist, it will almost surely fall well down on the list of causes that may be harmful to your health (on the other end of the list from your automobile). It does mean, however, that hams should be aware of the potential for exposure from their stations, and take whatever reasonable steps they can take to minimize their own exposure and the exposure of those around them.

Although the FCC doesn't regulate 60-Hz fields, some recent concern about EMF has focused on 60 Hz. Amateur Radio equipment can be a significant source of 60 Hz fields, although there are many other sources of this kind of energy in the typical home. Magnetic fields can be measured relatively accurately with inexpensive 60-Hz meters that are made by several manufacturers.

Table 28.4 shows typical magnetic field intensities of Amateur Radio equipment and various household items.

Table 28.4
Typical 60-Hz Magnetic Fields Near Amateur Radio Equipment and AC-Powered Household Appliances
Values are in milligauss.

Item	*Field*	*Distance*
Electric blanket	30-90	Surface
Microwave oven	10-100	Surface
	1-10	12 in.
IBM personal computer	5-10	Atop monitor
	0-1	15 in. from screen
Electric drill	500-2000	At handle
Hair dryer	200-2000	At handle
HF transceiver	10-100	Atop cabinet
	1-5	15 in. from front
1-kW RF amplifier	80-1000	Atop cabinet
	1-25	15 in. from front

(Source: measurements made by members of the ARRL RF Safety Committee)

Table 28.5
Typical RF Field Strengths Near Amateur Radio Antennas
A sampling of values as measured by the Federal Communications Commission and Environmental Protection Agency, 1990

Antenna Type	*Freq (MHz)*	*Power (W)*	*E Field (V/m)*	*Location*
Dipole in attic	14.15	100	7-100	In home
Discone in attic	146.5	250	10-27	In home
Half sloper	21.5	1000	50	1 m from base
Dipole at 7-13 ft	7.14	120	8-150	1-2 m from earth
Vertical	3.8	800	180	0.5 m from base
5-element Yagi at 60 ft	21.2	1000	10-20	In shack
			14	12 m from base
3-element Yagi at 25 ft	28.5	425	8-12	12 m from base
Inverted V at 22-46 ft	7.23	1400	5-27	Below antenna
Vertical on roof	14.11	140	6-9	In house
			35-100	At antenna tuner
Whip on auto roof	146.5	100	22-75	2 m antenna
			15-30	In vehicle
			90	Rear seat
5-element Yagi at 20 ft	50.1	500	37-50	10 m antenna

28.3.6 Determining RF Power Density

Unfortunately, determining the power density of the RF fields generated by an amateur station is not as simple as measuring low-frequency magnetic fields. Although sophisticated instruments can be used to measure RF power densities quite accurately, they are costly and require frequent recalibration. Most amateurs don't have access to such equipment, and the inexpensive field-strength meters that we do have are not suitable for measuring RF power density.

Table 28.5 shows a sampling of measurements made at Amateur Radio stations by the Federal Communications Commission and the Environmental Protection Agency in 1990. As this table indicates, a good antenna well removed from inhabited areas poses no hazard under any of the ANSI/IEEE guidelines. However, the FCC/EPA survey also indicates that amateurs must be careful about using indoor or attic-mounted antennas, mobile antennas, low directional arrays or any other antenna that is close to inhabited areas, especially when moderate to high power is used.

Ideally, before using any antenna that is in close proximity to an inhabited area, you should measure the RF power density. If that is not feasible, the next best option is make the installation as safe as possible by observing the safety suggestions listed in **Table 28.6**.

It also is possible, of course, to calculate the probable power density near an antenna using simple equations. Such calculations have many pitfalls. For one, most of the situations where the power density would be high enough to be of concern are in the near field. In the near field, ground interactions and other variables produce power densities that cannot be determined by simple arithmetic. In the far field, conditions become easier to predict with simple calculations. (See the February 2013 *QST* article "Q and the Energy Stored Around Antennas" by Kai Siwiak, KE4PT and the **Antennas** chapter of this book for more information about stored energy density near antennas.)

The boundary between the near field and the far field depends on the wavelength of the transmitted signal and the physical size and configuration of the antenna. The boundary between the near field and the far field of an antenna can be as much as several wavelengths from the antenna.

Computer antenna-modeling programs are another approach you can use. *MININEC* or other codes derived from *NEC* (Numerical Electromagnetics Code) are suitable for estimating RF magnetic and electric fields around amateur antenna systems.

These models have limitations. Ground interactions must be considered in estimating near-field power densities, and the "correct ground" must be modeled. Computer modeling is generally not sophisticated enough to predict "hot spots" in the near field — places where the field intensity may be far higher than would be expected, due to reflections from nearby objects. In addition, "nearby objects" often change or vary with weather or the season, therefore the model so laboriously crafted may not be representative of the actual situation, by the time it is running on the computer.

Intensely elevated but localized fields often can be detected by professional measuring instruments. These "hot spots" are often found near wiring in the shack, and metal objects such as antenna masts or equipment cabinets. But even with the best instrumentation, these measurements also may be misleading in the near field. One need not make precise measurements or model the exact antenna system, however, to develop some idea of the relative fields around an antenna. Computer modeling using close approximations of the geometry and power input of the antenna will generally suffice. Those who are familiar with *MININEC* can estimate their power densities by computer modeling, and those who have access to professional power-density meters can make useful measurements.

While our primary concern is ordinarily the intensity of the signal radiated by an antenna, we also should remember that there are other potential energy sources to be considered. You also can be exposed to excessive RF fields directly from a power amplifier if it is operated without proper shielding. Transmission lines also may radiate a significant amount of energy under some conditions. Poor microwave waveguide joints or improperly assembled connectors are another source of incidental exposure.

Table 28.6
RF Awareness Guidelines

These guidelines were developed by the ARRL RF Safety Committee, based on the FCC/EPA measurements of Table 28.4 and other data.

• Although antennas on towers (well away from people) pose no exposure problem, make certain that the RF radiation is confined to the antennas' radiating elements themselves. Provide a single, good station ground (earth), and eliminate radiation from transmission lines. Use good coaxial cable or other feed line properly. Avoid serious imbalance in your antenna system and feed line. For high-powered installations, avoid end-fed antennas that come directly into the transmitter area near the operator.

• No person should ever be near any transmitting antenna while it is in use. This is especially true for mobile or ground-mounted vertical antennas. Avoid transmitting with more than 25 W in a VHF mobile installation unless it is possible to first measure the RF fields inside the vehicle. At the 1-kW level, both HF and VHF directional antennas should be at least 35 ft above inhabited areas. Avoid using indoor and attic-mounted antennas if at all possible. If open-wire feeders are used, ensure that it is not possible for people (or animals) to come into accidental contact with the feed line.

• Don't operate high-power amplifiers with the covers removed, especially at VHF/UHF.

• In the UHF/SHF region, never look into the open end of an activated length of waveguide or microwave feed-horn antenna or point it toward anyone. (If you do, you may be exposing your eyes to more than the maximum permissible exposure level of RF radiation.) Never point a high-gain, narrow-bandwidth antenna (a paraboloid, for instance) toward people. Use caution in aiming an EME (moonbounce) array toward the horizon; EME arrays may deliver an effective radiated power of 250,000 W or more.

• With hand-held transceivers, keep the antenna away from your head and use the lowest power possible to maintain communications. Use a separate microphone and hold the rig as far away from you as possible. This will reduce your exposure to the RF energy.

• Don't work on antennas that have RF power applied.

• Don't stand or sit close to a power supply or linear amplifier when the ac power is turned on. Stay at least 24 inches away from power transformers, electrical fans and other sources of high-level 60-Hz magnetic fields.

28.3.7 Further RF Exposure Suggestions

Potential exposure situations should be taken seriously. Based on the FCC/EPA measurements and other data, the "RF awareness" guidelines of Table 28.6 were developed by the ARRL RF Safety Committee. A longer version of these guidelines, along with a complete list of references, appeared in a *QST* article by Ivan Shulman, MD, WC2S ("Is Amateur Radio Hazardous to Our Health?" *QST*, Oct 1989, pp 31-34).

In addition, the ARRL has published a book, *RF Exposure and You* that helps hams comply with the FCC's RF-exposure regulations. The ARRL also maintains an RF-exposure news page on its website. See **www.arrl.org/rf-exposure**. This site contains reprints of selected *QST* articles on RF exposure and links to the FCC and other useful sites.

SUMMARY

The ideas presented in this chapter are intended to reinforce the concept that ham radio, like many other activities in modern life, does have certain risks. But by understanding the hazards and how to deal effectively with them, the risk can be minimized. Common-sense measures can go a long way to help us prevent accidents. Traditionally, amateurs are inventors, and experimenting is a major part of our nature. But reckless chance-taking is never wise, especially when our health and well-being is involved. A healthy attitude toward doing things the right way will help us meet our goals and expectations.