RF Safety (excerpted for ARRL Handbook, 100th Edition (2023)

22.3 RF Safety

This section was written by Gregory Lapin, PhD, PE, N9GL, chair of the ARRL RF Safety Committee. The ARRL's RF Safety Committee reviewed this content. Additional material is available as supplemental information on the ARRL's RF Exposure web page at **www.arrl.org/rf-exposure**.

22.3.1 The Need for an RF Safety Program

We have all seen water boiling in a microwave oven. Microwaves are a type of RF energy that can harm our bodies if we are exposed to it at sufficiently high levels. This is why reasonable precautions are taken so that RF energy at the frequencies and levels used by amateur radio stations are safe.

Based on over 100 years of experience in amateur radio, operators who are regularly exposed to lower levels of RF energy have similar, and sometimes less, disease than the general population (see the sidebar "Standards, Science, and the Community"). Similar encouraging health outcomes from the vast majority of people on Earth who use cellular telephones on a regular basis indicate that when properly controlled, exposure to RF energy does not need to be a concern. Clearly, RF can be used safely.

To be dangerous, RF must be absorbed into tissue with sufficient power to cause heating for which the body cannot compensate. As licensed radio amateurs, we all need to ensure that our transmissions do not expose any people beyond the levels that have been deemed to be safe. Standards organizations have reviewed and analyzed scientific research that has been performed for over 60 years and derived safe levels of exposure for people. Regulatory agencies, such as the FCC in the United States, have developed regulations that require all operators of RF transmitters to maintain exposure levels below specified limits.

Modern research into the biological effects of exposure to electromagnetic energy has been taking place since the 1950s. The United States Navy sponsored much of the early research and, together with academics and the IEEE, formed the first electromagnetic exposure safety committee. This later evolved into the IEEE C95 family of standards on electromagnetic safety that include both recommended safety levels for exposure as well as recommendations for establishing RF safety programs.

An RF safety program should be developed for each amateur radio station. The program consists of an analysis of potential exposure levels around the station. If overexposure of people is possible, the program determines what forms of mitigation will be necessary to prevent anyone's exposure from exceeding the regulatory thresholds. Although not required by the FCC, documentation of the

The ARRL RF Safety Committee

The ARRL maintains an RF Safety Committee that is composed of scientific and medical experts in the many aspects of the study of RF safety. The RFSC serves as a resource to the ARRL Board of Directors, the ARRL Laboratory, and to the amateur community. It regularly monitors new scientific research and many of its members participate in the scientific committees that write safety standards for RF exposure. The RFSC participates in generating the RF safety questions for FCC amateur question pools and works with the FCC in developing its environmental regulations. For more information about the RFSC, see **arrl.org/arrl-rf-safety-committee**.

Standards, Studies, and the Community

You or your neighbors are likely to have questions about where standards for RF Exposure come from or how science evaluates the effect of RF on people. There are two papers on the **www.arrl.org/rf-exposure** web page and in this book's online information to help understand these questions: "RF Safety Standard Development" and "Types of Scientific Studies." To help you explain to your neighbors that amateur radio is safe because you operate your equipment safely, the discussion "How to Interact With a Concerned Neighbor" can make the conversation easier for everyone. Finally, there is so much information online with more coming out every day. "Interpreting the News About RF Exposure "Discoveries"" will help you deal with information that might be out of context or simply untrue. These documents will be helpful as you navigate questions about RF and amateur radio transmissions.

RF safety program should be filed away so that it can be referred to if there is ever any question about RF exposure from that station.

Part of RF safety is recognizing that non-ham acquaintances and family members may have concerns about RF exposure. The material in this section will help you explain what hazards exist and what steps you have taken to ensure that you are operating safely. Some people may have concerns that are difficult to address. For such cases, the ARRL provides "How to Interact With a Concerned Neighbor," which provides some guidance in responding. In addition, the Internet is a frequent source of information that is taken out of context or is simply false, which can also raise unwarranted concerns. The paper "Interpreting the News About RF Exposure "Discoveries" may be helpful when such issues are brought to you. Both papers are available at the ARRL's RF Exposure website, **www.arrl.org/rf-exposure**.

22.3.2 Effects of RF On the Body

NON-IONIZING RADIATION

When we speak of *radiation*, we are referring to the property of energy to move from one place to another, or radiate. The terminology has unfortunately been associated by the public with the energy that comes from radioactive devices, such as nuclear bombs, X-ray machines and other sources of ionizing radiation. When members of the public hear the word, *radiation*, they often think of danger.

There are two distinct types of photon energy that radiate: *Non-ionizing* and *Ionizing radiation*. These phrases refer to the ability of the energy contained in a photon to push electrons out of their orbits and ionize chemical compounds. When the chemicals in biological tissue are ionized, generally the tissue no longer functions properly. The photon energy of the radiation is what determines its potential to cause ionization; photon energy is directly proportional to frequency. Thus, electromagnetic energy with frequencies above the ionization limit are far more dangerous than photons at lower frequencies. The division between non-ionizing and ionizing radiation is in the ultraviolet light spectrum, with ionizing radiation having frequencies above 8×10^{14} Hz (800 THz).

The highest RF communications frequencies in use today are below 500×10^{9} Hz (500 GHz) and most amateur operations occur at frequencies far below that. Thus, amateur radio makes use of non-ionizing radiation that is thousands or millions of times below the frequency that would cause it to ionize tissue. This is significant since amateur radio transmissions have insufficient energy to ionize, or alter, DNA molecules in our tissue. Alteration of DNA molecules by ionization, such as with ultraviolet light, is generally believed to have the potential for causing cancer (which is why we wear sunscreen to filter out UV light from the sun in order to avoid skin cancer).

TISSUE HEATING

Even though non-ionizing radiation cannot alter tissue by rearranging its electrons, it can still cause damage with heat. The heat generated in tissue is proportional to the rate of RF energy absorption in the tissue; the rate of energy absorption is determined by the incident power density of the electromagnetic waves and the electrical properties of the tissue. Radiation interacts with any substance in three ways: it can reflect from its surface, it can pass through, and it can be absorbed. The portion that is absorbed is generally converted to heat. The human body core is referred to as *homeothermic*, meaning that body temperature is relatively uniform throughout the body and remains within a relatively narrow range. Your core body temperature is typically 98.6°F (37°C) and if your core temperature rises to be in excess of 104°F (40°C) your life could be danger.

The body has developed efficient methods to remove excess heat. Control of blood flow through tissue, sweating and breathing all are used in the tight control of tissue temperature. As long as the combined heat load resulting from the body's metabolic rate, heat absorbed from the environment and any heat generated by absorbed RF can be quickly and effectively removed by the body there is no danger of adverse health effects from the exposure. When the additional heat load from RF energy absorption exceeds the ability of the body to remove it, health can be compromised.

Heating vs Non-thermal RF Safety

RF safety exposure standards were originally based solely on the generation of heat from absorbed RF energy. The initial standards were derived from a single incident exposure limit of 10 mW/cm^2 for the entire spectrum of RF frequencies and assuming the body was exposed to a uniform field. Over time, this limit was revised to account for how the body absorbs RF energy differently at different frequencies, analogous to an antenna capturing more power from an RF field at its resonant frequency and less at non-resonant frequencies.

While the effects of heating from absorption of RF energy are easily calculated, there have been a number of demonstrations of biological effects from exposure to electromagnetic energy. For instance, in the laboratory, change of the operation of calcium channels in isolated cells exposed to levels of electromagnetic energy too low to cause measurable heating has been demonstrated. A number of other non-thermal effects have been demonstrated in the laboratory.

Although reports of RF effects in isolated cells in the laboratory is of interest to the scientific understanding of biological effects of electromagnetic energy exposure, such reports remain inconclusive as to the potential for causing adverse health effects in humans. To address this, the standards bodies have based their decisions about safe exposure levels on scientific studies that demonstrate deleterious effects on animals or on calculated body and tissue temperature increases presumed to be unsafe. Once the thresholds of potentially adverse effects have been determined, safety factors have been applied to arrive at acceptable exposure limits that include a margin of safety.

22.3.3 RF Safety Standard Development

Most of what we know about operating with safe exposure levels comes from over 60 years of scientific study of how electromagnetic energy affects biological tissue. Thousands of studies have been summarized by standards bodies that then identified levels of exposure considered to be safe. The two most recognized standards bodies are the IEEE International Committee on Electromagnetic Safety, ICES, and the International Commission on Non-Ionizing Radiation Protection, ICNIRP. The FCC has based its exposure regulations on both the IEEE C95.1-1991 standard and recommendations from a scientific group chartered by the U.S. Congress, the National Council on Radiation Protection (NCRP), in their NCRP Report #86. To read more about the history of electromagnetic standards development see RF Safety Standard Development on the ARRL's RF Exposure web page (**www.arrl.org/rf-exposure**).

TYPES OF SCIENTIFIC STUDIES

There are two basic types of scientific studies that are used to determine the limits of safe exposure to electromagnetic energy. Laboratory studies use either isolated cells or animals to test for effects of highly controlled exposures. Epidemiological studies focus on the incidence of adverse effects or diseases in the population to try to identify trends that may be related to some type of exposure. All scientific studies must deal with the biological variations between various individuals. Natural variations are separated from the effects of the stimulus under examination by examining large populations of subjects that have been exposed to the stimulus (study population) and those that have not (control population). If the number of subjects studied is large enough and all variables and stimuli except the stimulus under study are identical between the study and control populations, statistical analysis will point to any effects that are associated with the stimulus in question. To read more about scientific studies, including epidemiological studies of amateur radio operators, see Types of Scientific Studies on the ARRL's RF Exposure web page (**www.arrl.org/rf-exposure**).

Neither type of study can be conclusive as to the formation of a disease or production of some form of adverse reaction. An epidemiological study can indicate an association between a given stimulus and disease. Laboratory experimentation can shed light on the mechanisms that may cause disease, but neither type of study on its own is capable of proving a causal link between RF exposure and human disease.

All scientific studies are made public through the process of peer review. The results of a study are written as a scientific article, which briefly reviews previous work on that subject, specifies the methods that were used to obtain the reported results, presents the results and then includes an interpretation of the results. The written report of a study is submitted to a scientific journal, generally which specializes in the topic of the current study. The journal sends copies of the report to a number of peer reviewers, who use their expertise in the subject to critique the study and, after it is acceptable to the peer experts, is then published in the journal. The process of peer review has been widely considered an acceptable gate keeper that separates good from bad science.

In recent years, there has been evidence that the peer review process is not infallible. Many scientific publications that clearly do not have the scientific basis to make the claims that they do have been published as having been peer reviewed but appear to have bypassed the process. There are several ways that this has been done. For instance, papers that are not accepted by journals in their field are sometimes resubmitted to journals in other fields where the peers are not experts in the topic of the paper.

The scientific publication process also includes the ability for other peers, who were not asked to review a paper, to comment on science that they do not agree with. The comments are published in future editions of the journal and the original authors are given the opportunity to reply. Often, the comment and reply process is not followed with the original paper that is being challenged.

As weaknesses in the peer review process have become more evident, one tool that the scientific community has come to rely on is independent replication of results. If a scientific study provides results that contradict what has been seen in the past, it is important that the new results be confirmed by an independent laboratory that follows that first study's procedures. Often, independent replication is able to identify errors in the original study that led to the unique results.

22.3.4 FCC RF Exposure Requirements

The FCC is given the responsibility under the National Environmental Policy Act of 1969 to control the operations of stations that it regulates to prevent adverse effects on the environment. In 1996, this duty was expanded to prevent the signals from all transmitters, including those of the Amateur Radio Service, from causing excessive human exposure. Since the FCC is not a health and safety agency, it relied on accepted RF safety standards and advice from the FDA to develop its rules. The bases of the FCC safety thresholds were NCRP Report #86 and ANSI/IEEE C95.1-1992, which were discussed earlier.

SAR vs MPE

As per the safety standards, the FCC defined *maximum permissible exposure* (MPE) limits in terms of the power absorbed in tissue, the *specific absorption rate* (SAR). A fixed, safe SAR value applies across the frequency spectrum and is defined for exposure of the whole body or of a specific area (local exposure); at lower frequencies in the range of whole-body resonance, the whole body averaged SAR (in watts per kilogram of body mass) is the appropriate limit. At higher frequencies with exposures from antennas that are close to the body, localized SAR (in watts per kilogram of tissue, measured in a small amount of tissue, either a single gram or ten grams in size) becomes a more important measure of exposure.

It is very difficult to measure or model SAR. To measure SAR, one would have to place a probe directly in the tissue at many locations and monitor the rate of absorbed electromagnetic energy over time. Modeling SAR is also complicated, since the varying shapes of anatomical structures and their electromagnetic properties have to be modeled over the entire body. While these tasks are not impossible, they are complex enough that few amateur licensees would have the ability or means to determine if exposure from their stations exceeds the FCC limits.

In contrast to determining SAR, electromagnetic energy in the air is much easier to either measure or model. To make the exposure limits easier to follow, the standards bodies developed equivalences between electromagnetic energy incident on the surface of the body and the whole-body SAR that would result. Even though the safe SAR limit is fixed across the spectrum, the actual SAR that results from exposure, both within the body as a whole and within different organs, depends on frequency.

The relationship between wavelength and the sizes and shapes of the body and its organs causes resonances in some frequency ranges that result in more energy being absorbed. In **Figure 22.22**, which represents MPEs recommended by the ANSI/IEEE C95.1-1992 standard, this effect is clear. The average human body and its larger structures are most resonant to frequencies in the VHF range, and because of this the MPEs in that frequency range are the lowest. Where the difference between wavelength and the size of body structures is greater, both at VLF, LF and low HF frequencies, and at microwave and

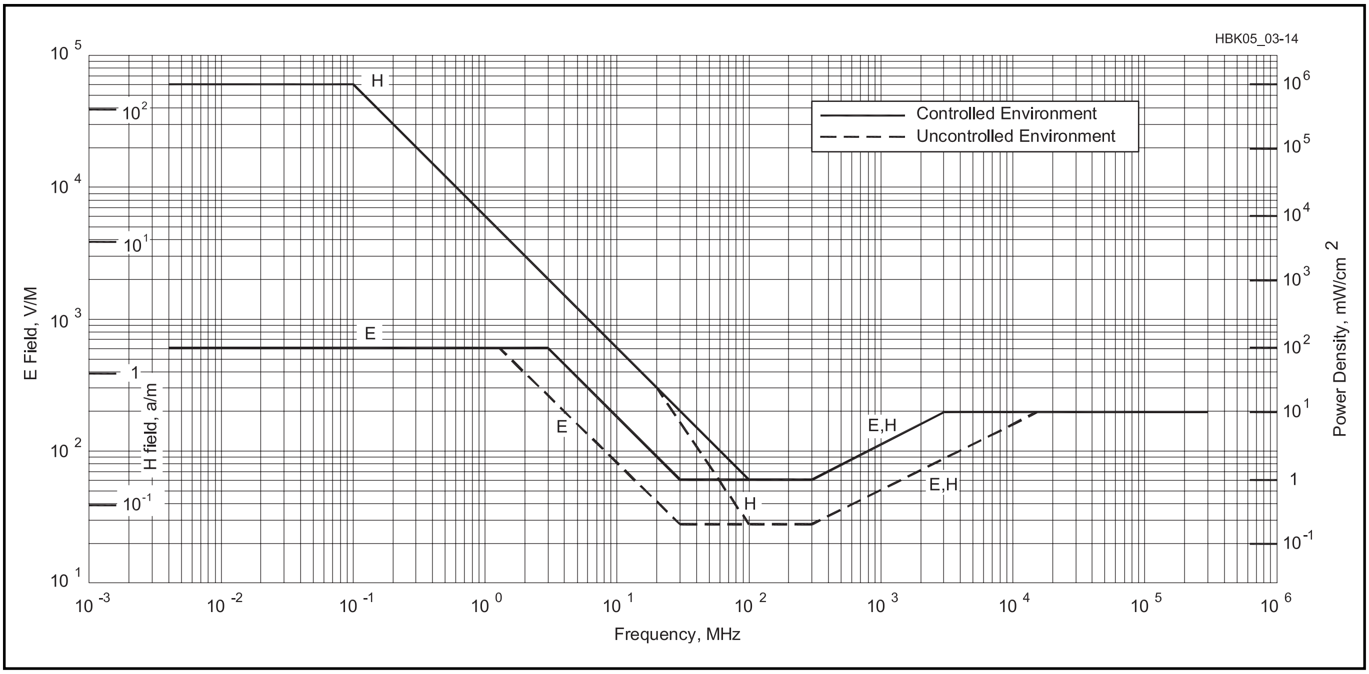

Figure 22.22 — 1991 RF protection guidelines for body exposure of humans. It is known officially as the "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz."

higher frequencies, absorption is less and the MPEs are higher.

At lower frequencies the interaction between electromagnetic energy and the human body differs for the electric and magnetic components of the energy. Because of this, different MPEs exist for the electric (E) field (in V/m) and the magnetic (H) field (in A/m) up to 300 MHz and both limits must be met. Above 300 MHz the MPE limits are expressed only by the power density (in mW/cm^2). It is common to measure or model power density at frequencies below 300 MHz but in doing so, one must be careful to obtain plane-wave equivalent power density. In the far-field, the power density at all frequencies is determined from a plane-wave but in the near-field, before the energy resolves into a plane-wave, the power density must be derived from both the E- and the H-fields at any location.

The graph in Figure 22.22 is also expressed in tabular form, as in **Table 22.4**. The FCC has published their MPE limits in that form in their rules, in §1.1310(e). Unlike the plots in Figure 22.22, power density is also shown in the table for frequencies below 30 MHz, under the condition that it be plane-wave equivalent power density.

Table 22.4
(From §1.1310) Limits for Maximum Permissible Exposure (MPE)
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 in Table 22.5).

LOCALIZED EXPOSURE

The MPEs in the FCC rules presume uniform whole-body exposure. This may or may not be the case for typical amateur radio stations. In some circumstances, exposure is mainly limited to a portion of the body. Handheld radios are an example of this. When you hold a handheld radio in front of your face, most of the exposure from its antenna is to your head. The FCC uses a distance of 20 cm (about 8 inches) between the antenna and any portion of a person's body to distinguish between whether whole body MPE can be used for assessing compliance with their rules, or if a localized SAR determination must be made. For any antenna that is used less than 20 cm from a person, the only acceptable form of exposure determination is SAR.

Since SAR determination is beyond the capabilities of most radio amateurs, it is expected that manufacturers of handheld radios will perform that test and provide the results to the amateur, who will be able to use those data to comply with the FCC exposure requirements. This requirement became official on May 3, 2021, and any handheld radios manufactured before that time are assumed to meet the exposure requirements even without SAR testing by the manufacturer. In support of this supposition, a survey study of the FCC equipment database to see what SAR measurements have revealed for commercial handheld devices that are similar to amateur radio handhelds found that commonly used handheld transmitter power levels did not cause overexposure. This limited study showed that in commercial handheld devices at frequencies just above the amateur 2-meter band with similar power output and rubber duck antennas the SAR measurements were below the FCC SAR limits. Similar results were seen for devices that operated at frequencies just above the amateur 70 cm band.

Occupational vs General Population

The ANSI/IEEE C95.1-1992 standard makes a distinction between what is termed the occupational population, or *controlled environment*, and the general public, or *un-*

controlled environment. The reasoning for creating two sets of safety limits was to provide an additional margin of safety for people who were unaware of their exposure. The use of controlled and uncontrolled environments in the IEEE standard also helps emphasize that the IEEE standard does not restrict the higher set of exposure limits only to those who may be occupationally exposed. For example, the IEEE context is that the upper set of exposure limits, those for controlled environments, apply to anyone who is aware of the potential for exposure, not just to those who may be exposed because of their occupation.

This is in contrast to the FCC exposure rules wherein controlled exposures generally apply only to exposure encountered as a result of one's occupation, with the caveat that anyone considered to be in the occupational population must also be trained about RF safety.

The additional safety margins for general population/uncontrolled exposures are generally 5-times greater than those applicable to the controlled environment, which themselves already result in exposures that are 10-times lower than the exposure levels at which any deleterious effect had been detected in scientific studies. Thus, those individuals in uncontrolled environments are protected by limits that are 50-times lower than exposures at which deleterious effects have been demonstrated in scientific studies.

Radio amateurs and the people living in their households were included in the FCC rules to be considered part of the occupational population subject to the more permissive exposure limits. This gives amateurs more leeway in designing their RF safety programs, since the people living in their houses are subject to the higher MPE values. Questions on RF exposure were added to each of the amateur radio licensing exam question pools as evidence of training for licensed amateurs. Radio amateurs are expected to educate the people living in their homes about the potential for RF exposure caused by operation of their stations and how to reduce exposure if they so desire.

TIME AVERAGING

The MPEs are based on eliminating the whole-body heating effects caused by RF exposure. Because of the thermal time constant of the body, exposures are averaged over any six-minute period. This process results in controlling the approximate average level of thermal load imposed on the body. The time averaging permits short exposure to very high-power signals followed by very low exposure, which has the same effect on the body as a continuous lower exposure, as long as the average does not exceed the MPE over the designated averaging time. For the occupational population the averaging time is 6 minutes; for the general population it is 30 minutes.

MODULATION DUTY CYCLE

Averaging is defined in two ways for amateur radio operations. Many forms of modulation cause the peak power of the carrier to vary over time, and the average of those variations is lower than the exposure that would be caused by the unmodulated carrier. Some common averaging duty cycles for typical amateur radio modulation types are shown in **Table 22.5**.

TRANSMIT-RECEIVE DUTY CYCLE

During the exposure averaging times of 6- or 30 minutes, typical amateur communication switches from transmit-to-receive several times. Since exposure occurs only during the transmit portion of the conversation, that represents another duty cycle that can be combined with the modulation duty cycle to determine the overall time-averaged value of exposure. A typical voice conversation between two radio amateurs would have each station transmitting for 50% of the time. In a contesting situation, the transmit duty cycle could either be much less, with short calls and longer times listening or higher with frequent CQ calls and short pauses for a reply. Each amateur should make a best estimate of the duty cycle of transmission in their form of operating.

The transmit-receive duty cycle has meaning only in situations where transmissions are significantly shorter than the averaging period. For instance, if an amateur transmits continuously for 6 minutes and then listens for 6 minutes, the duty cycle for assessing the occupational exposure, with a 6-minute averaging time, is 100%, since the full averaging time can be used during one transmission. However, for this same transmit-receive timing in calculations for exposure of the general population, with a 30-minute averaging period, the duty cycle is 50%.

ACTUAL EXPOSURE AFTER AVERAGING

The exposure that is calculated for a person standing near an antenna can be lowered by factoring in both the modulation duty cycle and the transmit-receive duty cycle. For instance, if you calculate that when standing in a certain location near a 10-meter dipole, a person in the general public could be exposed to the equivalent of 1.0 mW/cm^2, a power density that exceeds the FCC MPE of 0.2 mW/cm^2 by a large margin, you may then apply the duty cycles of your operation. In this example, you normally operate with uncompressed SSB and converse with a friend where you each talk for one minute and listen for one minute. Your modulation duty cycle in this case is 20% (factor of 0.2) and your transmit-receive duty cycle is 50% (factor of 0.5). The averaged exposure of the person in question would then be:

1.0 mW/cm^2 x 0.2 x 0.5 = 0.1 mW/cm^2

Therefore, this location meets the FCC MPE for the general population when the station is operated as described. However, if you were to switch your modulation from SSB to FM, the average exposure would change markedly. Frequency modulation has a modulation duty cycle of 100% (factor of 1.0) and, with all other operating parameters being the same, the averaged exposure of the person in question would become:

1.0 mW/cm^2 x 1.0 x 0.5 = 0.5 mW/cm^2

which is more than double the FCC MPE for the general population.

22.3.5 Responsibilities of the Radio Amateur

The FCC expects every amateur radio licensee to abide by its exposure rules. Even when you are not required to perform a complicated analysis, it is your responsibility to make sure that no person is ever exposed above the MPE listed in the FCC rules, with

Table 22.5

Limits for General Population/Uncontrolled Exposure

Frequency Range (MHz)	*Electric Field Strength (V/m)*	*Magnetic Field Strength (A/m)*	*Power Density (mW/cm^2)*	*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: Pd = |Etotal|2 / 3770 mW/cm^2 or from $P_d = |H_{total}|^2 \times 37.7$ mW/cm^2.

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

the understanding that the MPE table refers to values of plane wave equivalent power density that are averaged over applicable times and spatially averaged over the dimensions of the body.

There are several ways to evaluate the exposure from your amateur radio station. The simplest forms of evaluation are designed to be highly conservative so that any operation passing the evaluation is highly unlikely to ever cause overexposure to any person near the antennas. However, this conservatism may cause one to think that their operating parameters need to be changed while a more exact analysis may show that no overexposure would occur. For instance, the FCC provides exemptions from more detailed analysis applying calculations that indicate what the maximum transmitted power must be for a person standing a given distance from an antenna. In a given situation, the exemption formulae may tell you that you need to reduce power from what you planned to use. If that occurs, a more detailed form of analysis might show that your power setting would not actually cause overexposure and your planned power level will be permitted.

For the purposes of exposure analysis, it is not necessary to determine the exact levels to which people might be exposed. It is only necessary to affirm that any exposure will less than the FCC MPE thresholds. Any assessment method that provides credible confirmation without determining the exact exposure is perfectly acceptable when demonstrating compliance with the FCC human exposure rules.

Most stations will require multiple analyses to account for differences in operating modes, antennas, transmitters, and frequency bands. It is not necessary to use the same analysis methods for each set of operating parameters and, generally, the simplest method that shows compliance with the FCC MPEs is the best to use.

The FCC does not require that amateurs submit the results of their exposure assessments to the commission. However, it is wise to document the assessments and file them so that if there is ever a question about overexposure from your station, you will be able to provide documentation to show why that is not the case.

Many radio amateurs will find that the simplest forms of exposure assessment are satisfactory for their station's operations. Descriptions of the two most common methods are found below. More complicated assessments are beyond the scope of this discussion. If they should become necessary, other documents, including some that are referenced here, can provide appropriate guidance that you will need.

As you read this chapter about the federal regulations and requirements for compliance with RF exposure rules, it may seem a bit overwhelming in terms of both regulatory and technical detail. Perhaps the most useful guidance to new amateur radio licensees is to design your station to comply with these rules in the first place and choose conservative operational practices will help you avoid unnecessary trouble in the future. If you are a seasoned amateur licensee with a long-established station that may have never given any serious attention to RF safety in the past, now is the time to use the information in this chapter to help you review all aspects of your station that could lead to excessive RF exposures and, where appropriate, take those steps that will get your station into compliance.

PERFORMING AN EXPOSURE ASSESSMENT

Before choosing what type of exposure assessment is needed, there is certain information that must be gathered, which will be used with any assessment. These are:

1. The amount of power that will be emitted from the antenna

The measure of power that is important in the analysis of exposure is the amount that is emitted from the antenna. You need to know the output power of the transmitter, the loss in your feed line and the gain of your antenna. The FCC has standardized on effective radiated power (ERP) to define emitted power; ERP is the net power delivered to the antenna multiplied by the power gain of the antenna relative to a half wave dipole in free space. The simplest way to calculate ERP is to first convert transmitter output power to dBW (dB with respect to a watt, e.g., 100 watts = 20 dBW). Next subtract the feed line loss, which is reported by coaxial cable manufacturers in dB/100 feet at various frequencies. Choose the closest frequency that is reported by the manufacturer and factor in the length of your coaxial cable. Finally, add the gain of the antenna in dBd (dB with respect to a half wave dipole). Some antenna manufacturers report the gains of their antennas in dBi, the gain with respect to an isotropic radiator. To convert from dBi to dBd, subtract 2.15 dB (i.e., dBd = dBi - 2.15).

If you have a power amplifier that you use occasionally, try using that high power output in the analysis. If the method you are using suggests that exposure may not comply with the MPE, you can analyze with and without the amplifier separately. Clearly, if analysis with the higher transmit power indicates no potential exposure problems, then it is not necessary to repeat the analysis with the barefoot power level.

2. The shortest distance there will ever be between any part of the antenna and a person

Some methods of exposure assessment distinguish between exposure to people in the occupational population and exposure to the general population. This can be important for some stations since the FCC MPE values for the occupational population are significantly less stringent. The FCC has designated licensed radio amateurs and the members of their households as members of the occupational population, so it may be necessary to perform two analyses for each antenna on each band, with the distance from the antenna to the nearest people in the occupational population used in one calculation and the distance from the antenna to the nearest people in the general population used in the other calculation.

FCC EXEMPTIONS

The current FCC rules allow for "exemptions" from performing more detailed exposure evaluations. As mentioned earlier, however, there is no exemption from complying with the FCC exposure regulations!

The first requirement for the use of FCC exemptions is that the distance between a person and the nearest point of the antenna be outside the reactive field region of the antenna, which is greater than $\lambda/2\pi$, where λ represents the wavelength of the signal being transmitted. **Table 22.6** gives the minimum distances from the antenna for which the FCC exemptions can be used for most amateur bands.

If the shortest distance between a person and any part of the antenna (R), expressed in meters, will be less than the values on Table 22.6, then a different exposure evaluation method must be used. To determine if you are exempt from further, more detailed, evaluation, you can use the expressions in **Table 22.7** for your frequency range of interest to calculate the threshold ERP that will ensure compliance with the exposure rules. The calculation result tells you the maximum power that can be emitted from the antenna (ERP) in order to maintain the exemption. Take care to match your units. The FCC exemption formulas are based on distances in meters, while you may have made your measurements in feet. The result of the exemption is ERP in watts, while you may have calculated your ERP in dBW.

Table 22.6
Minimum Exemption Distances ($\lambda/2\pi$)

Band *(MHz)*	Distance	Band *(MHz)*	Distance
1.8	87.0 ft	24.9	6.3 ft
3.6	43.5 ft	28.2	5.6 ft
3.9	40.2 ft	50.1	3.1 ft
7.1	22.1 ft	146	1.1 ft
10.1	15.5 ft	223	8.4 in
14.1	11.1 ft	440	4.3 in
18.1	8.7 ft	902	2.1 in
21.2	7.4 ft	1296	1.5 in

Table 22.7
Maximum Exempt ERP

	Frequency (MHz)	Maximum ERP (Watts)
VLF	0.3 – 1.34	$1920 \times R^2$
HF	1.34 – 30	$3450 \times R^2 / f^2$
VHF	30 – 300	$3.83 \times R^2$
UHF	300 – 1500	$0.0128 \times R^2 \times f$
MW	1500 – 100,000	$19.2 \times R^2$

Note: R is distance in meters and f is frequency in MHz.

Example Calculations:

On 14.1 MHz at 10 meters from the antenna, the maximum exempt ERP is $3450 \times 10^2 / 14.1^2 = 1735$ W.

On 22.2 MHz at 10 meters from the antenna, the maximum exempt ERP is $3450 \times 10^2 / 22.2^2 = 433$ W.

On 50.1 MHz at 5 meters from the antenna, the maximum exempt ERP is $3.83 \times 5^2 = 96$ W.

On 146 MHz at 0.5 meters from the antenna, the maximum exempt ERP is $3.83 \times 0.5^2 = 0.96$ W.

Normally, FCC exemptions must be recalculated for each frequency band that will be used by a station. Some peculiarities of the equations allow you to decrease the number of calculations. For instance, in the equation for the HF bands (1.34–30 MHz) the frequency parameter is in the denominator. If you are using the same multiband antenna for several HF bands, by calculating the threshold ERP for the 10 meter band, as the frequency decreases for the other HF bands then the threshold ERP will only get larger. Calculation at the highest frequency used by an antenna in the HF bands gives the worst case, or lowest allowable threshold ERP. No additional calculations are necessary for lower frequencies on the same antenna as long as the exemption is valid for the highest frequency used and the minimum exposure distance remains greater than $\lambda/2\pi$ for all lower frequency bands being considered.

For VHF bands (30 – 300 MHz) the exemption formula does not vary with frequency, so you need only perform one calculation per antenna (with unchanging power levels), no matter how many VHF bands are transmitted by that antenna.

On UHF bands (300 – 1500 MHz) the exemption formula is proportional to frequency so a calculation at the lowest frequency in that range for an antenna is the only one needed for all frequencies transmitted from that antenna. In these bands, an exposure distance greater than $\lambda/2\pi$ could still be less than 20 cm. Recall that any exposure distance less than 20 cm must be evaluated with SAR, and these exemption formulae would not apply (see the note near the bottom of Table 22.7).

DISADVANTAGES OF USING EXEMPTIONS

Even though determining if you qualify for the exemption from more detailed evaluation is easy, the analysis process makes certain assumptions that tend to overestimate exposure. If the calculations with the exemption criteria yield acceptable ERP values for your station, then there is nothing else to do and your exposure analysis is complete. You can presume that operation of your station will comply with the FCC RF exposure rules.

If, however, the application of the exemption criteria indicates that you must decrease your ERP below what you planned to transmit, then the highly conservative assumptions associated with the process may be the culprit and not the potential exposure that would result from your station's operation. When an exemption calculation specifies a maximum allowable ERP, the assumption is that the antenna gain is equal in all directions. Even though a directional antenna is often rotated through a full circle, the regions above and below the antenna are never subject to that much gain, and there can be significant attenuation in the transmitted pattern that is not accounted for with this analysis method.

The exemption process assumes that members of the general population will be exposed at the previously determined shortest access distance to the antenna and applies the more restrictive general population MPE for finding a compliant ERP. It could be that only the amateur and/or members of the household will have such access and, in this case, the less stringent occupational/controlled exposure MPEs are actually applicable.

Further, the exemption determination does not factor in the modulation and transmit-receive duty cycles, which usually decreases the actual averaged exposure.

Finally, the exemption criteria also make the generally unrealistic assumption that perfect reflection of RF fields from the ground occur as if it was a perfectly conducting surface. This assumption, by itself, increases the potential exposure field power density by up to a factor of four. Hence, the exemption criteria represent a highly conservative approach that will in most cases overestimate potential exposure levels but can be regarded as a fail-safe approach for compliance assessment.

If the exemption process indicates that your station needs to decrease power to operate below the general population MPE, you should consider a more accurate form of analysis (see below) and confirm whether the individuals who have access to your antenna at the distance you determined will be members of the general population or just the licensed operator and members of the operator's household for which the less restrictive MPEs apply.

ONLINE CALCULATORS

Several RF field calculators for estimating potential exposure are available on the Internet. Most are based on calculation in the far-field; some assume a free space environment while others permit inclusion of a ground reflection factor that increases the calculated field strength or power density. It is important to use a known online calculator. The calculations performed in the background of an online calculator may contain unwarranted assumptions or even outright errors that are invisible to the user. The calculator must compare the results of its power density calculations to the proper exposure limits; in the United States that must be the current FCC MPEs and, if they are ever changed, the calculator must be modified to produce the correct results. The calculator that you use should explicitly state which thresholds are being used with its calculations.

Even though the calculation is based on an equation for far-field power densities, the results for simple antennas are applicable in the near-field and even in the reactive near-field, which is not valid for FCC exemptions and may still be overly conservative. Other assumptions used in the FCC exemptions are also true for most online calculators, mainly that the antenna gain can occur in all directions. However, most online calculators will distinguish between the exposure distances for the occupational population and the general population.

A good example of an online RF exposure calculator can be found on the ARRL website at **arrl.org/rf-exposure-calculator**. A sample calculation is shown in **Figure 22.23**. This calculator requires that you determine the feed line loss and enter the power at the antenna. However, for simplicity, you may want to first perform the calculations as if there was no feed line loss and see if it gives favorable results. If not, then you can go to the additional work of calculating the feed line loss to see if that makes an important difference for your station's exposure calculation.

This calculator factors in the modulation and transmit-receive duty cycles. It asks for antenna gain in dBi. The results are the minimum compliance distances from the antenna to people in the occupational population and to people in the general population in both feet and meters. Remember that the averaging times for the FCC MPEs are different for the two different population groups and that the averaging times refer to either a six-minute or 30-minute "sliding window" of time. Thus, the transmit-receive duty cycle must take into account the ratio of the maximum transmit time during any six-minute or 30-minute period to the averaging time period.

The ARRL online calculator also allows for applying a realistic ground reflection factor

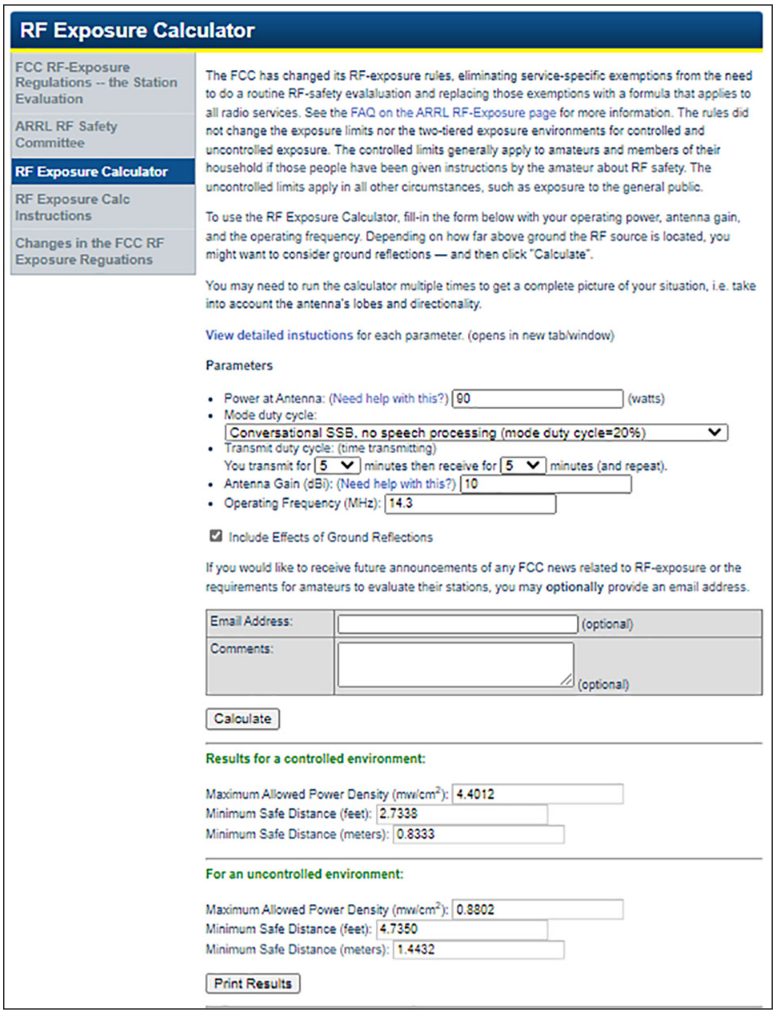

Figure 22.23 — ARRL RF Exposure Calculator.

of 2.56 when calculating power density or no reflection factor at all (as in free space). This means that the calculator is intended for more realistic estimation of expected RF field power density, which is suitable for certifying compliance with the FCC MPEs. This is in contrast to applying the FCC exemption criteria proposed for an initial go/no go indication as to whether additional evaluation effort will be necessary.

WHEN SHOULD ONLINE CALCULATORS NOT BE USED?

Online calculators that are based on the far-field equation also give accurate exposure results as close as the surface of the antenna for some simple antenna types. It is important, however, to not use this form of analysis too close to more complex antennas. The exposure calculator does not ask you what type of antenna you are using and if it reports a short compliance distance, that would only be accurate for a simple wire antenna. If the shortest distance between a person and the antenna is much larger than the calculated compliance distance, the result may still be valid. A good distance to use for this determination is the same one that is used by the FCC exemptions, the reactive near-field, or $\lambda/2\pi$, as shown in Table 22.6. If the distance to the nearest person is greater than the value in that table and the calculator gives a compliance distance less than that, it can still be used even for a complex antenna.

22.3.6 RF Exposure Mitigation

It is not the purpose of the FCC human exposure regulations to keep you off the air. The goal is preventing overexposure of anyone while you are operating. If your calculations indicate that locations at which people may be present could cause exposure exceeding the FCC MPE (an overexposure), you must perform some type of mitigation to prevent that occurrence. There are many ways that you can mitigate an overexposure situation, some of which may actually improve the performance of your station.

If possible, when areas in which an overexposure could occur exist on the ground, raising the antenna could do away with the problem. For antennas that have sections mounted close to the ground, such as the ends of an inverted-V, raising those ends by even a few feet could convert a noncompliant station into one meeting the FCC MPEs.

POSITIVE ACCESS CONTROL

The FCC requires *positive access control* (PAC) to prevent people from accessing areas in which they might be overexposed. PAC is a general term that refers to an active measure that keeps people from entering overexposure areas. PAC can be as simple as a locked door to a rooftop on which antennas are located. A common way to achieve PAC is to place effective fencing around the areas where access must be controlled.

Wherever PAC is used, the FCC requires that signs be posted to warn about the possibility of overexposure. Signs must be large enough to be read from a distance at which overexposure cannot occur. The content of the sign is specified in the FCC rules, and, for areas in which the FCC general population MPE may be exceeded, must have the word "NOTICE" in white letters on a blue banner along with a description of the hazard and your contact information. If exposure to RF fields within the controlled area have the potential to exceed the FCC occupational population MPE, then the sign must have the word "CAUTION" in black letters on a yellow banner along with similar text as the "NOTICE" sign.

OPERATING MODIFICATIONS

Two conditions must be met to cause exposure: the station must be transmitting and there must be a person present in a potential overexposure area. PAC is a means of preventing the latter. However, control of the former can also satisfy the requirement that no person be exposed to electromagnetic energy exceeding the MPEs.

The FCC writes its regulations to cover all forms of radio transmission that they regulate. Some of these include broadcast transmitters and cellular base stations. Both of these differ from amateur radio in two ways: they transmit during all hours of every day of the year and, most importantly, they are usually unattended. In contrast, amateur radio transmissions are generally intermittent, and the amateur radio operator is usually present at the transmitter while it is operating.

If a person enters a potential overexposure area and the amateur radio operator then stops operating, no hazard exists, and the station remains compliant with the FCC rules on exposure. Similarly, the amateur radio operator may determine that a lower transmit power removes the hazard, and then decreases the power any time a person is seen to enter the overexposure area.

Amateur radio stations that are remotely controlled require special considerations when identifying areas in which individuals might be exposed above the FCC MPEs. For remote operations, the best approach is to design the transmitting site to be inherently compliant with the MPEs without need for real time monitoring of activity within the area.

22.3.7 RF Safety References

The preceding section has presented an introduction to the reasons for developing an RF Safety program for your station and some basic procedures to help determine what areas around your station may be a cause for concern that a person might be exposed to your transmitted signals beyond the limits that the FCC has set. To perform more exact exposure analyses, which may be necessary if your station has marginal exposure results from the more common methods, you can look to the following references:

FCC OET Bulletin 65

The FCC has provided guidance for complying with their rules on human exposure to electromagnetic energy in their OET Bulletin 65. OET Bulletin 65 Supplement B, which was principally written by members of the ARRL RF Safety Committee, provides more specialized information that applies to the operation of an amateur radio station. Both of these documents are available for free download from the FCC website: **www.fcc.gov/general/oet-bulletins-line**.

ARRL Antenna Book

The *ARRL Antenna Book* has an RF Safety section that builds on the information provided here. Additional information is provided to help perform more exact exposure modeling with the Numerical Electromagnetic Code (NEC), with a discussion of the importance of ground reflections and spatial averaging. A discussion of the use of Pre-Assessed Configurations (PACs) to more accurately estimate the potential RF exposure around specific antenna types and installations is also included. That section discusses specialized antennas that are more difficult to assess and how to handle exposure around unattended repeaters and other remote stations. Finally, the subject of VLF transmissions and induced limb currents is discussed in the anticipation that this additional measure of exposure may be added to the FCC regulations in the future.

RF Exposure and You

The ARRL has published a book entitled *RF Exposure and You*, which delves into all aspects of RF exposure and how to comply with FCC regulations.

SCIENTIFIC REPORTS AND STUDIES

ANSI/IEEE C95.1-1992: IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz. Note: The IEEE C95.1-1991 standard was adopted by the American National Standards Institute, ANSI, in 1992.

NCRP Report #86: Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields, 1986.

Tell, R., "Amateur portable radios (handheld transceivers): exposure considerations based on SAR." *QEX*, Jul./Aug. 2021, pp. 11 – 15.

Jordan, E., and Balmain, K., *Electromagnetic waves and Radiating Systems,* 2nd Edition (Prentiss-Hall, 1968) pp. 333 – 338.