CDC 4B051

Bioenvironmental Engineering Journeyman

Volume 4A. Occupational and Environmental Health (OEH) Risk Assessment: Radiation

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THIS FOURTH VOLUME, part A of Career Development Course (CDC) 4B051, *Bioenvironmental Engineering Journeyman,* covers foundational concepts, information and procedures regarding radiation physics as well as bioenvironmental engineering's (BEE) role and the duties associated in dealing with radiation safety. Unit 1 introduces the general principles of energy and mass, including the specific types of radiation. Unit 2 addresses electromagnetic frequency radiation and outlines procedures for measuring the radiation, assessing the associated risks, and assigning controls. Unit 3 discusses laser radiation. Unit 4 discusses the sources, hazards, and controlled associated with ultraviolet and infrared radiation.

A glossary is included for your use.

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To get a response to your questions concerning subject matter in this course, or to point out technical errors in the text, unit review exercises, or course examination, call or write the author using the contact information provided in this volume.

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For Guard and Reserve personnel, this volume is valued at 16 hours and 4 points.

References

American National Standards Institute (ANSI) Z136.1, *Safe Use of Lasers.*

USAFSAM *Technical Guide to Lasers and Optical Radiation* (AFRL–SA–WP–SR–2013–0011).

USAFSAM Environment, Safety, and Occupational Health (ESOH) Service Center Laser Homepage (https://hpws.afrl.af.mil/dhp/OE/ESOHSC/index.cfm).

AFI 48–139, *Laser and Optical Radiation Protection Program*, 25 July 2012. Certified current, 22 April 2020

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

Page

Unit 1. Radiation Overview

RADIATION IS ONE OF the more complex areas of study within the bioenvironmental engineering (BE) career field. This is, in large part, due to that fact that it cannot be tasted, smelled, or heard; it can only be seen or felt in a limited range (as light and heat). This unit discusses electromagnetic frequency (EMF), visible radiation, and ionizing radiation, and distinguishes how radiation and matter interact, radiation's health effects, and protective measures that can be taken. BE's role regarding radiation will be presented, followed by a more detailed discussion of specific information and concepts.

601. Roles and interactions of bioenvironmental engineering in radiation safety

The BE career field plays an important role both in garrison and deployed in the control and management of radiation. Educating and protecting individuals from radiation hazards requires a BE technician to interact with many individuals and organizations basewide. Air Force Manual (AFMAN) 48-148, *Ionizing Radiation Protection,* defines radiation source as "any non-exempt quantity of radioactive material (RAM), equipment, or devices which spontaneously generate or are capable of generating ionizing radiation." This can include anything from RAM on a nuclear weapon, to industrial x-rays taken of aircraft, to equipment used on construction sites. The installation radiation safety officer (IRSO) on each base (usually BE) must work with the unit radiation safety officers (URSO) and permit radiation safety officers (PRSO) to ensure installation radiation safety.

Roles of the installation radiation safety officer

The wing/installation commander appoints a person with specific qualifications to be the IRSO. The IRSO is the focal point for all aspects of radiation protection, including ionizing and non-ionizing radiation. Key responsibilities of the IRSO include:

- Coordinating installation radiation safety activities.
- Reviewing procedures and practices periodically, facility design and classification, training, exposure control, and monitoring and surveillance activities.
- Developing installation radiation safety operating instructions or radiation safety manuals.
- Managing the distribution and recordkeeping requirements of the personnel dosimetry and bioassay program.

For most installations, the IRSO duties will be assigned to the base BE; however, in order to assure a sound radiation safety program, assistance from everyone within the BE flight is required. In the absence of a qualified officer, the senior BE technician or other qualified individual will perform IRSO duties (as specified in AFMAN 48-148).

The IRSO will also interact with the United States Air Force (USAF) Radioisotope Committee Secretariat (RICS), which is managed under the Air Force surgeon general's office. With the exception of certain weapons-related materials outlined in the Atomic Energy Act, the RICS provides regulatory oversight for the use of RAMs by Air Force (AF) organizations. The IRSO is the RICS's main point of contact for any radiation protection issues or concerns on an AF installation.

Interactions with other base agencies

BE personnel interact with other individuals on the installation concerning radiation protection. Each organization with RAM will have a commander-appointed URSO. The URSO is the unit commander's point of contact for radiation protection matters. The IRSO works with URSOs to investigate suspected overexposures and the development of unit-specific radiation safety and training programs.

Deployed locations may offer unique challenges, regarding radiation safety that are not inherent in garrison. Depending on the deployed location, there may be radiation sources both on and near the installation that need to be assessed for health threats. While conducting an occupational and environmental health site assessment (OEHSA) and toxic industrial chemical/toxic industrial material (TIC/TIM) assessment, experience shows coordination with the following agencies will help gather data on existing radiation threats:

- Civil engineering.
- Security forces.
- Airfield operations.
- Anti-terrorism officer.
- Host nation liaison.

The BE career field also plays a significant role in the installation's non-ionizing radiation safety program, including functions such as:

- Conducting EMF health hazard evaluations for new systems, operations, and modified systems in use on the installation.
- Providing guidance and recommendations regarding engineering controls, personal protective equipment and warning devices, posting requirements, and other administrative controls as necessary.
- Assisting unit commanders and workplace supervisors in the development of EMF safety awareness training programs.
- Investigating all alleged or suspected overexposures.

Refer to Air Force Instruction (AFI) 48-109, *Electromagnetic Field Radiation (EMFR) Occupational and Environmental Health Program*, for a listing of all BE flight responsibilities relating to EMF radiation.

602. Fundamental concepts of energy and mass

Understanding the relationship between energy and mass is fundamental in the study of radiation. The *Law of Conservation of Energy* states that energy can neither be created nor destroyed but can change from one form to another. This means that the total amount of energy in a system remains constant and cannot be increased nor decreased. Energy can be broken down into two main states:

- Kinetic energy: Object in motion (also referred to as "energy of motion").
- Potential energy: Stored energy (also referred to as "energy of position").

Figure 1–1 shows an example of a pencil having a certain amount of potential energy in relation to the floor; a quantity of work will be converted to kinetic energy when it drops. The same pencil on the second floor of a building has more potential energy in relation to ground level simply because of the greater distance and increased kinetic energy done when it drops. An object with more mass at the same height will have even more potential energy. Potential energy cannot do anything by itself but must first be converted to kinetic energy. In the case of the pencil, when it begins its descent, the potential energy is then converted to kinetic energy.

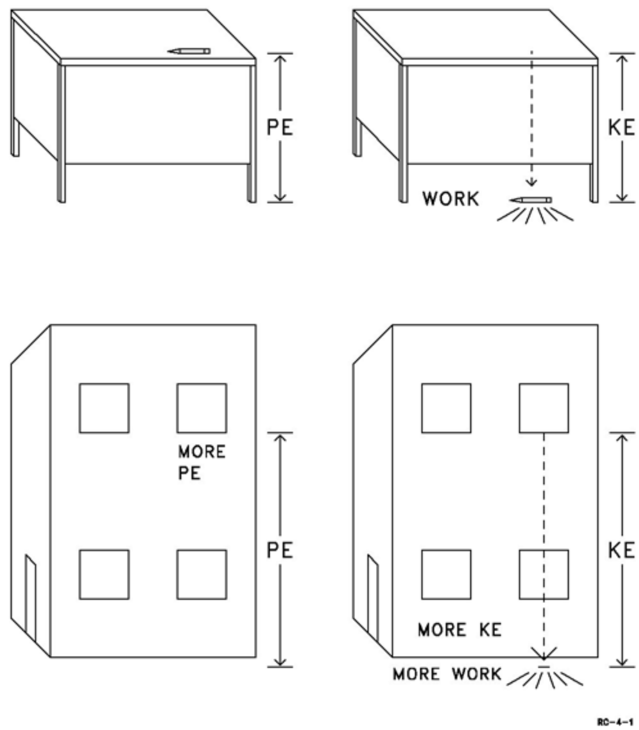

Figure 1–1. Potential and kinetic energy.

Electrons orbit a nucleus in one of seven electron shells. The electron shell in which the electrons travel is directly proportionate to the amount of kinetic energy contained within the electron. As the electrons' distance (in orbit) increases, the kinetic energy of electrons increases as their orbital distance increases away from the nucleus. The amount of kinetic energy is typically expressed in units of electron volt (eV). One eV is the amount of energy (kinetic) that an electron gains when it is accelerated in an electric field produced by one volt (fig. 1–2). The eV relates to the more common units of energy (the erg or the joule) as follows:

- 1 eV is equal to approximately 1.6 x 10^{-12} erg.
- 1 eV is equal to approximately 1.6 x 10^{-19} joule.

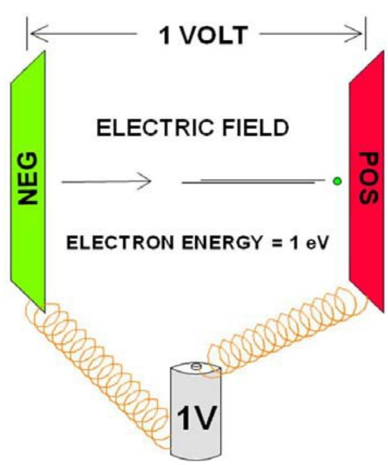

Figure 1–2. Electron volt.

Similar to the *Law of Conservation of Energy*, the *Law of Conservation of Mass* states that mass can neither be created nor destroyed. In chemical reactions and mixing operations, the total mass within a system will remain constant before and after each process. With nuclear energy, however, it becomes a little more complicated. Albert Einstein discovered that energy and mass can be converted using the relationship $E=mc^2$. This is important when considering the concept of mass defect and binding energy.

Mass defect and binding energy

If the total mass of each proton, neutron, and electron of a given element is added up, the total mass is slightly more than the actual mass of the element. This difference in mass is called mass defect. The mass defect is the mass that is converted to energy to hold the atom together. Mass defect is also referred to as binding energy. This is the amount of energy required to break apart an atom or the amount of energy released when the atom is broken apart. The larger the binding energy, the more difficult is to break apart a given atom. Even though the amount of energy released per atom is very small, a very large number of atoms can occupy a small space. When they all break apart over a short period of time, a tremendous amount of energy can be released.

603. Electromagnetic radiation and the spectrum

The electromagnetic (EM) spectrum is a vast band of energy that travels through space in waves. These waves travel at the speed of light but can vary in wavelength and frequency. The spectrum extends from very long waves with very low frequency (radio waves) to very short waves with high frequencies (gamma rays). Since every wave has the same amount of energy, the shorter the interval between waves (high frequency [HF]), the more energy carried. The frequency (and its corresponding wavelength) determines the type of EM radiation as shown in figure 1–3.

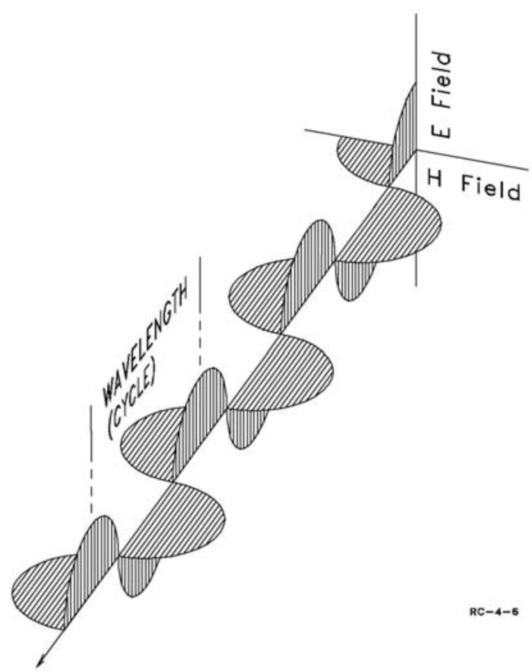

Figure 1–3. EM wave.

Radio waves, radar, microwaves and most light carry only enough energy to move electrons in atoms to a higher energy state and are known as non-ionizing radiation**.** Some ultraviolet light, and all x-rays and gamma-rays carry enough energy to remove electrons from atoms, so they are known as ionizing radiation. Since different atoms have different ionization potentials, the point where the energy transitions from non-ionizing to ionizing varies with the makeup of what is absorbing the energy. Though the generic term radiation technically applies to the entire spectrum, most people only associate the term with ionizing radiation and microwaves. Overcoming this misconception tends to be one of the challenges with establishing a radiation safety program.

Wavelength and frequency

It is useful to think of the individual portions of the wave as cycles, because of the graphical depiction of "cycling" up and down (fig. 1–4). The wavelength is the distance from a point on one cycle (usually taken at the top) to the same point of the next cycle. This distance is typically given in meters or some multiple of meters (kilometer [km], nanometer [nm]) depending upon the area of the spectrum under study.

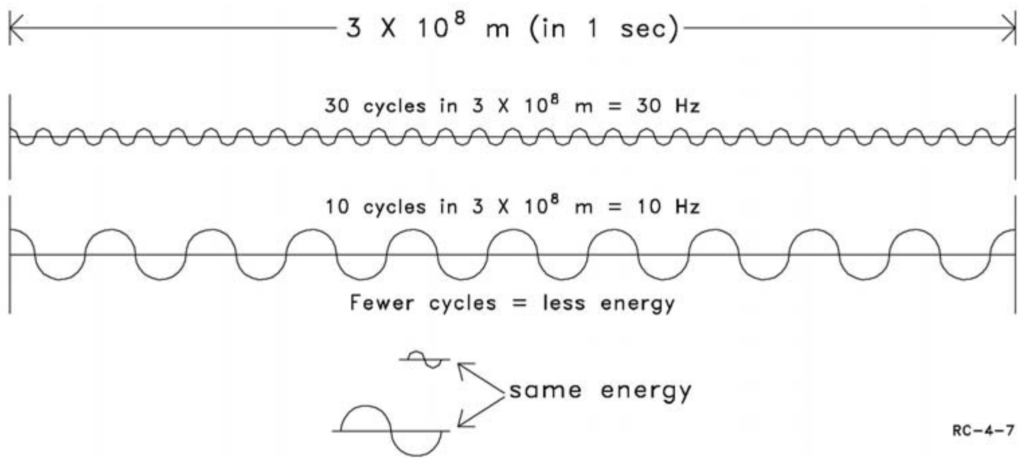

Figure 1–4. Relationship of wavelength, frequency, and energy.

The frequency of the radiation at a given point in the spectrum refers to how frequently the cycle occurs each second. Consider the number of cycles passing a certain point in one second. The older units of measure for frequency, cycles per second (cps) are now called "hertz" (Hz). Multiples of this are expressed as kilohertz (kHz — 1000 Hz), megahertz (MHz — 1,000,000 Hz), and gigahertz (GHz — 1,000,000,000 Hz). Since the radiation travels at the speed of light (3×10^8 meters per second), the frequency can be depicted as the number of cycles of a certain size that will fit into the distance traveled in one second. For example, 30 cycles that are 10 million meters long will fit into the distance of 3×10^8 meters, which yields a frequency of 30 Hz.

Wavelength, frequency, and velocity have the following corresponding symbols:

- **Wavelength** = λ (which is the Greek letter lambda).
- **Frequency** = ν (which is the Greek letter pronounced "new").
- **Velocity** = c (constant, as it is always equal to the speed of light).

The basic formula for relating these variables is:

$$c = \lambda\nu$$

This is the length of each cycle multiplied by the number of cycles. This must always equal the velocity of light. Since the speed of light is constant, this equation demonstrates that if one variable increases (e.g. wavelength), the corresponding variable (e.g., frequency) must decrease.

NOTE: It is important to use the same length units for velocity and wavelength. Use meters per second when the wavelength is in meters and centimeters per second when the wavelength is in centimeters, and so forth. If the more easily understood units of cycles per second for the frequency and meters per cycle for the wavelength are used, dimensional analysis shows that the velocity must be in meters per second.

Energy

Radiation of a certain wavelength and frequency also has an exact energy associated with it. Each cycle, no matter how long or short, has the same amount of energy as every other cycle. The energy level is known as "Planck's constant" (h), which is equal to 4.14×10^{-15} eV per cycle. The energy (E) of an EM wave of a certain frequency and wavelength is determined by multiplying the number of cycles occurring in one second by the energy of each cycle (Planck's constant times the frequency).

$$E = h\nu$$

Where:

E	= energy
h	= Plank's constant (energy of each cycle)
ν	= frequency (number of cycles occurring per second)

To find the energy with only the wavelength, first convert the wavelength to its corresponding frequency. A higher frequency means a higher energy carried (directly proportional), while a longer wavelength means a lower energy carried (inversely proportional).

An EM wave can also be thought of as an individual "bundle of energy" called a photon or "discrete quanta of energy." Each photon travels and interacts with mass as a single exact, or discrete, quantity of energy. This can be a confusing concept because, although it has no mass, the radiation behaves as a wave under some circumstances and as a particle (photon) under others.

Wavelength and frequency are best described in terms of waves, while certain phenomena concerning the energy seem to indicate a particle. The amount of photon energy gives an idea of how much the radiation can affect atomic structure. As explained previously, a high-energy photon may cause a higher energy state in an atom (excitation). Radiation with even more energy may "kick" an electron from its orbit (ionization) as if the photon were a particle hitting another particle.

Intensity

The intensity of EM radiation refers to the amount of energy flowing through a given area in a certain amount of time. The units of intensity vary according to the type of radiation. Typical examples are watts per square meter (W/m^2) and milliwatts per square centimeter (mW/cm2). A 25-watt bulb emits a large number of photons of varying energies per square centimeter every second. A 100-watt bulb emits many more per square centimeter per second. All EM radiation from point sources follows the inverse square law: *the intensity decreases by a **factor of four** when the distance from the source is **doubled***. This will be covered more in the calculations portion of this volume.

604. Types of radiation

The parts of the EM spectrum are identified in different ways. One type of radiation may be identified by its frequency, while another is expressed having a certain wavelength or energy. In the overlapping parts of the spectrum, the same radiation can be differentiated in two ways, depending on the particular use. At the far end of the ultraviolet area, for example, the radiation is discussed in terms of wavelength if it is an ultraviolet application or as energy if it is considered x-ray radiation. A general overview will help with understanding the different types of radiation. As discussed above, the two major categories are non-ionizing and ionizing.

Non-ionizing radiation

Non-ionizing radiation includes EMF, infrared (IR), visible light, and ultraviolet. Non-ionizing radiation does not have the required energy to alter the structure of atoms and molecules. The main concern with non-ionizing radiation is its ability to heat tissue and cause other harmful biological effects (such as blisters and blindness). Four types of non-ionizing radiation are described below.

Electromagnetic frequency (also known as radiofrequency)

Radiation on the EM spectrum is pure energy (no particles). EMF radiation encompasses everything within the range of 3×10^3 to 3×10^{11} Hz. This category of radiation contains emitters with which most people are associated. Those that operate at the lower frequencies, such as amplitude modulation (AM)/frequency modulation (FM) radio and communications, are relatively safe to use and operate. Those at the higher EMF range, such as microwaves and radar, pose a more significant health hazard.

Infrared, visible, and ultraviolet

The IR, visible**,** and ultraviolet radiations are all identified by their wavelength. IR (meaning below red) is produced by food warmers, paint drying lamps, sunlamps, and many other devices used for situations requiring heat. Although not a direct application of IR, it is commonly emitted by furnaces and molten metals and glass. IR radiation generally poses the least potential for overexposure. This is because IR radiation has a built-in warning device—heat. Most people will move away from the source when it becomes too hot. However, shorter wavelengths, such as those used in lasers, can injure the cornea, iris, retina, and lens of the eye.

There is no clear-cut point at which IR becomes visible radiation, or the part of radiation that can be seen, because some people can see a broader range of radiation than other people. Discussion of visible radiation is provided for the purpose of establishing its relationship to other radiation types. BE addresses radiation only in the visible range when applied to lasers (unit four of this volume). It is necessary, however, to discuss “ultraviolet (UV)” (beyond violet).

UV radiation finds the most use in high intensity lamps. These devices require a glass shield around them to prevent human injury. A tanning booth is an example of this type of radiation. The sun is the most prominent source of UV radiation; the rays emitted from this radiation (UV rays) cause skin to burn. UV radiation is also encountered in welding operations and lasers.

Ionizing radiation

Ionizing radiation is the higher energy range of the EM spectrum. It can separate orbital electrons from within atoms to create ions. An ion is an atom that has more or less electrons than protons causing it to have an electric charge and, therefore, be chemically reactive.

X-ray and gamma radiation are types of ionizing radiation; both can knock electrons from their orbits. This electron displacement may lead to changes in living cells, such as cell dysfunction or even death.

A few places where ionizing radiation sources may be found include a wide range of occupational settings, such as apparatus in health care facilities, research institutions, nuclear reactors, nuclear weapon production facilities, and other manufacturing settings. If not properly controlled, these radiation sources can pose a considerable health risk to affected workers. If improperly used, ionizing radiation has the most significant health effects and should be closely monitored. Ionizing radiation can be caused by both high energy waves (x-ray and gamma ray) and particle radiation (alpha, beta, and neutron).

X-rays and gamma rays

X-rays and gamma rays consist of high-energy waves. The waves can travel great distances in air (several hundred feet or more). They are very penetrating and used in many Air Force applications, including:

- Medical operations:
  - Nuclear medicine.
  - Radiology department.
  - Sterilization procedures.
  - Dental x-rays.
- Non-destructive inspection.
- Various hand-held detectors.

Despite their ability to penetrate other materials, in general, neither gamma rays nor x-rays can irradiate materials (make them radioactive). Several feet of concrete or a few inches of dense material (such as lead) can block most of the energy from these types of radiation. X-rays and gamma rays can cause whole body internal or external exposures depending on whether the source is inside or outside a person's body.

Particle radiation

The EM spectrum, however, is not the only place where radiation is found. In contrast to the massless form of ionizing radiation (x-rays and gamma rays), alpha, beta, and neutron radiation (sometimes called "particle radiation"), have definite mass and, under certain circumstances, can present serious dangers. Particle radiation is emitted by an unstable nucleus during radioactive decay.

Sources of radiation

Most people are frightened by the term radiation, but in fact, there is radiation around us all the time. Sources of radiation are divided into three categories:

- Naturally occurring radiation.
- Background radiation.
- Artificial (man-made) radiation.

Naturally occurring radiation

Naturally occurring radiation is present from normal environmental causes and can be found in the soil, water, vegetation, and even within our own bodies (internal radiation). Radiation found in the soil, water, and vegetation is also known as terrestrial radiation. The major isotopes of concern with this type of radiation are uranium and the decay products of uranium (such as thorium, radium, and radon). Low levels of uranium (and its decay products) can be found everywhere. Some of these materials are ingested in food and water, while others, such as radon, are inhaled. The dose from terrestrial sources varies in different parts of the world; areas with higher concentrations of uranium and thorium in their soil will obviously have higher dose levels. This is especially true of radon, as one of the decay products of uranium.

Background radiation

Background radiation is due to naturally occurring radiation in the environment (as described above), man-made contamination (such as nuclear weapons testing and the Chernobyl and Fukushima nuclear reactor accidents), and cosmic radiation. Cosmic radiation occurs when charged particles from the sun and stars interact with the atmosphere and earth's magnetic field to produce a shower of radiation. This phenomenon is known as cosmic rays (typically beta and gamma). Exposure can also occur from commercial products such as older television sets, fluorescent lamps, smoke detectors, and tobacco products.

Artificially produced (man-made) radiation

In addition to background radiation, we also receive exposure from man-made radiation sources. Most of us are familiar with diagnostic imaging uses of x-rays in medicine and airport-style security systems. When man-made radiation is commercially used, public doses must be controlled. Likewise, individuals being occupationally exposed to radiation must be closely monitored. In addition to well-known occupationally exposed individuals such as nuclear medicine technicians or the radiography specialist in a hospital, AF workers being occupationally exposed to man-made radiation can be found on construction sites, numerous industrial areas, and research facilities.

Radioactive materials

Thanks to technology and the ability to take advantage of their properties, RAMs are also a concern in many areas of the AF. Naturally occurring RAM is gathered and concentrated for use in many fields. Sometimes RAM is created through industrial processes to meet technology needs. The use and application of RAMs include the fields of research, construction, energy, and combat. When RAM is collected and used, the risk of exposure is increased. For this reason, radiative substances must be carefully controlled.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit

601. Roles and interactions of bioenvironmental engineering in radiation safety

1. What are the key responsibilities of the IRSO?

2. Who will perform IRSO duties at installations without an engineer?

3. At a deployed location, who should you seek out and work with as part of conducting an OEHSA and why?

602. Fundamental concepts of energy and mass

1. A wheel (or pencil) at rest at the top of a ramp holds what type of energy?

2. What units are used to express energy?

3. What is mass defect?

603. Electromagnetic radiation and the spectrum

1. Which kind of wave in the EM spectrum has the most energy?

2. When wave frequency is increased, what happens to the wavelength and the energy carried?

3. How is the energy of an EM wave determined?

604. Types of radiation

1. How are the parts of the EM spectrum identified?

2. What is the reason there is usually little problems with IR radiation?

3. Which type of radiation is used in medical applications to treat cancer?

4. What can happen when ionizing radiation passes through living tissue?

Answers to Self-Test Questions

601

1. Key responsibilities of the IRSO include:
   a) Coordinating installation radiation safety activities.
   b) Reviewing procedures and practices periodically, facility design and classification, training, exposure control, monitoring and surveillance activities.
   c) Developing installation radiation safety operating instructions or radiation safety manuals.
   d) Managing the distribution and recordkeeping requirements of the personnel dosimetry and bioassay program.
2. In the absence of a qualified officer, the senior BE technician or other qualified individual will perform IRSO duties as specified in AFMAN 48-148.
3. 1. Civil engineering.
   2. Security forces.
   3. Airfield operations.
   4. Anti-terrorism officer.
   5. Host nation liaison.

602

1. Potential energy: stored energy (also referred to as “energy of position”).
2. eV; kinetic energy: object in motion (also referred to as “energy of motion”).
3. The mass defect is the mass of an atom that is converted to energy to hold the atom together.

603

1. Every wave has varying amount of energy; however, more energy is carried when the interval between the waves (higher frequency) is shorter.
2. The shorter the interval (wavelength) will decrease and more energy will be carried (increased).
3. The energy (E) of an EM wave of a certain frequency and wavelength is determined by multiplying the number of cycles occurring in one second by the energy of each cycle.

604

1. One type of radiation may be identified by its frequency, while another is expressed having a certain wavelength or energy.
2. IR radiation has a built-in warning device—heat.
3. Particle radiation is emitted by an unstable nucleus during radioactive decay.
4. Background radiation is due to naturally occurring radiation in our environment, man-made contamination (such as nuclear weapons testing and the Chernobyl and Fukushima nuclear reactor accidents), and cosmic radiation.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (601) Which entity provides regulatory oversight for the use of radioactive materials by Air Force (AF) organizations?
   a. United States Air Force (USAF) Radioisotope Committee Secretariat (RICS).
   b. Radiation safety committee (RSC).
   c. USAF surgeon general's office (USAF/SG).
   d. Environmental Protection Agency (EPA).

2. (601) Who is the unit commander's point of contact for radiation protection matters?
   a. Unit radiation safety officer.
   b. Command radiation safety officer.
   c. Installation radiation safety officer.
   d. Unit radiation safety committee officer.

3. (602) A rock rolling down a hill contains what form of energy?
   a. Kinetic.
   b. Velocity.
   c. Potential.
   d. Centrifugal.

4. (602) As the kinetic energy in electrons increases, the
   a. closer they are to each other.
   b. closer they are to the nucleus.
   c. farther they are from each other.
   d. farther they are from the nucleus.

5. (603) The number of electromagnetic waves passing a certain point in one second is known as
   a. energy.
   b. intensity.
   c. frequency.
   d. wavelength.

6. (603) As the frequency becomes higher, wavelength becomes
   a. slower.
   b. longer.
   c. faster.
   d. shorter.

7. (603) The amount of energy flowing through a given area in a certain amount of time refers to what measure of electromagnetic radiation?
   a. Activity.
   b. Frequency.
   c. Intensity.
   d. Wavelength.

8. (604) A tanning booth is a good example of which type of radiation?
   a. Gamma.
   b. Visible.
   c. Infrared.
   d. Ultraviolet.

Please read the unit menu for unit 2 and continue ➔

Unit 2. Electromagnetic Frequency Radiation

ULTRAVIOLET, VISIBLE, INFRARED, and EMF radiation are in the nonionizing radiation group. Although nonionizing radiation photon energies are too low to ionize atoms and molecules, they are sufficient to harm those exposed, and therefore, need to be assessed to control associated health risks. Each portion of the EM spectrum has its own uses and hazards.

2–1. Overview of Electromagnetic Frequency Radiation

There are several different types of antennas used for transmitting or receiving EMF radiation. The wide use of devices that produce EMF drives researchers to strive to better understand the characteristics of EMF radiation in order to keep protection standards adequate. To ensure compliance with established protection standards, it is important to be familiar with EMF radiation behavior and terminology.

605. Principles of electromagnetic frequency radiation

EMF radiation (fig. 2–1) encompasses the portion of the EM spectrum containing microwave radiation, radiofrequency radiation (RFR), and sub-RFR. The EMF radiation frequency ranges from 3,000 to 300,000,000,000 Hz. Multiplier prefixes are used somewhat interchangeably (listing the EMF range as 3 kHz to 300 GHz); so, it is important to learn them well enough to make almost instantaneous conversions between them.

- 1 kHz = 1000 Hz
- 1 MHz = 1,000,000 Hz
- 1 GHz = 1,000,000,000 Hz

The EM spectrum also corresponds to radiofrequency band designations. Note that what is called “high frequency” for radio waves are not particularly high frequencies on the EM spectrum (infrared, visible light, ultraviolet, and ionizing radiation all have higher frequencies).

- **VLF** = very low frequency
- **LF** = low frequency
- **MF** = middle frequency
- **HF** = high frequency
- **VHF** = very high frequency
- **UHF** = ultrahigh frequency

- **SHF** = super high frequency
- **EHF** = extremely high frequency

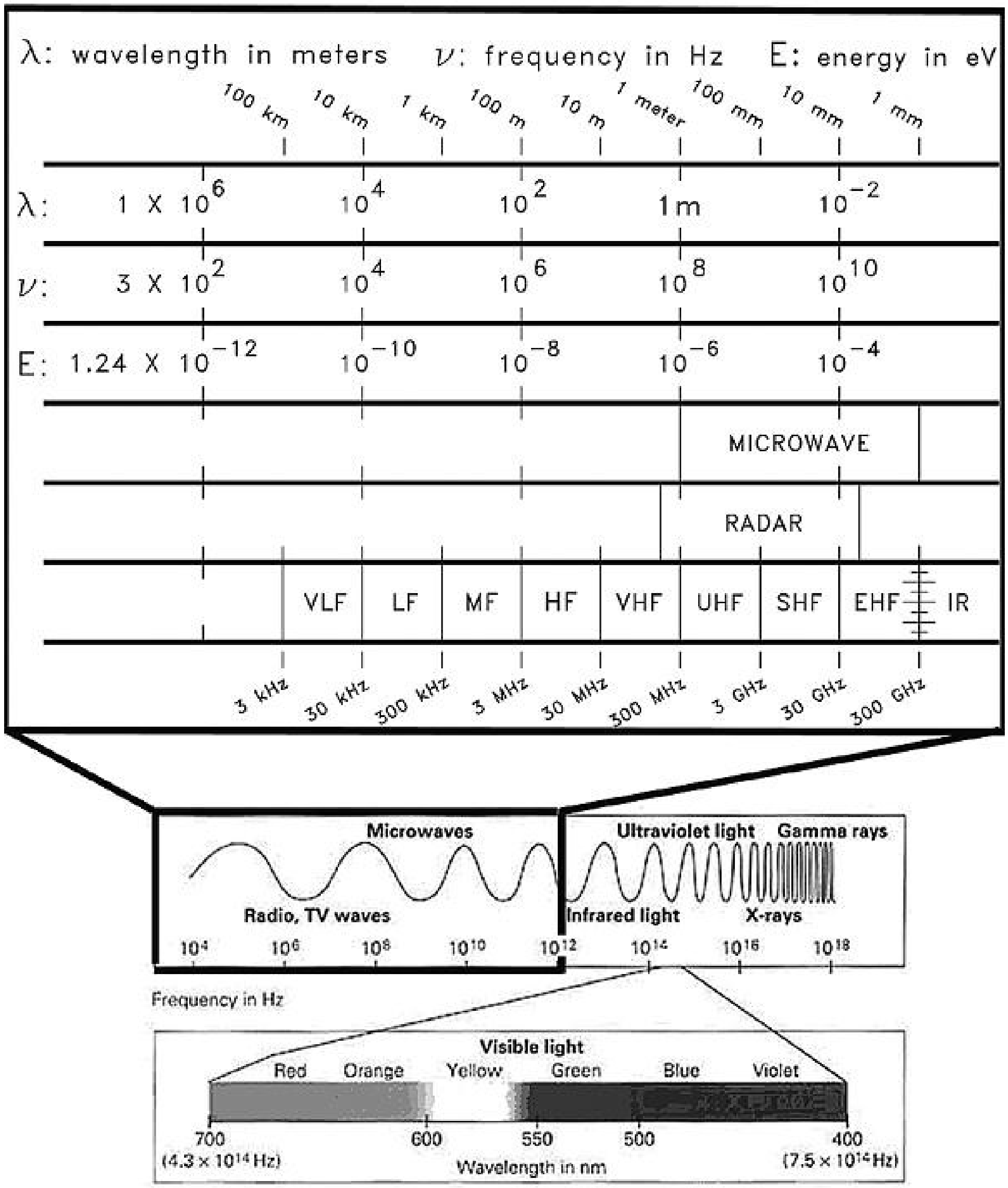

Figure 2–1. EMF radiation is part of the EM spectrum containing microwave, radio, and sub-radio frequencies.

Characteristics of electromagnetic frequency radiation

Understanding EMF radiation begins with understanding how electric and magnetic waves are generated. When an electric current changes direction, such as along an antenna, charged particles vibrate. Every electric current has an associated magnetic field. The current-induced vibrations and their associated magnetic fields create electric (E) and magnetic (H) waves that travel at the speed of light (about 3×10^8 meters per second) at a specific frequency, wavelength, and energy. These waves are called EM radiation. EMF radiation can, therefore, be described as the transfer of energy through space and matter by electric and magnetic fields.

Transmissions begin in a region called the near field (near the antenna) where the electric and magnetic fields develop. Within a few wavelengths, the fields begin to support each other at right angles (fig. 2–2) creating a region known as the far field (farther from the antenna). Electric fields are created by voltage differences; higher voltages create stronger fields which can be measured in volts per meter (V/m). Magnetic fields are created by flowing electric current, where greater electric currents create stronger magnetic fields. Magnetic fields can be measured in amperes per meter (A/m). Remember that electric and magnetic fields are pure energy; they have no mass and no charge.

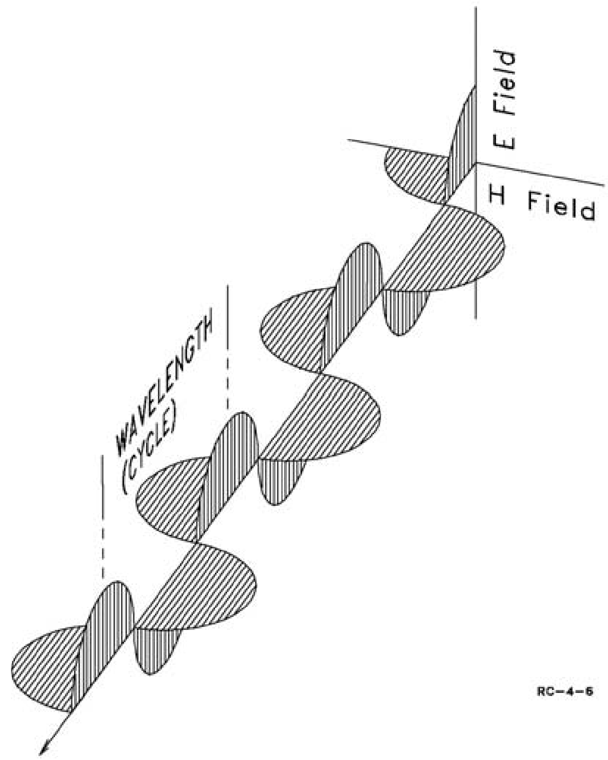

Figure 2–2. EM wave.

Electromagnetic frequency radiation production

Three basic equipment components (fig. 2–3)—transmitter, transmission line, and antenna—are common to all EMF radiation emitters.

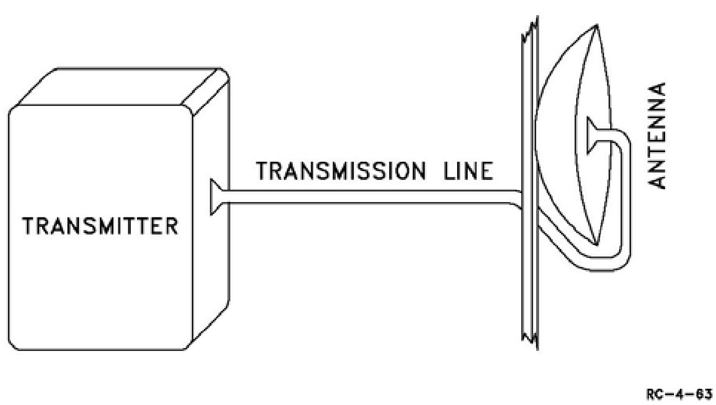

Figure 2–3. Basic EMF equipment components.

Transmitter

The transmitter generates and amplifies the EMF signal. The active components of transmitters can range from transistors and diodes used in low-power hand-held radios, to the high-powered microwave emitters in radar units. There are a variety of types, but two general types include a "continuous wave" (CW) transmitter that produces a constant signal, or a "pulsed" transmitter that cycles power on and off many times per second. Transmitters are generally rated by the watts (W) of power they transmit, but they can also be rated by decibels (dB). The decibel power rating can be either the power output relative to one watt, and abbreviated dBW, or the power relative to one milliwatt (mW), and abbreviated dBm.

Transmission line

The job of the transmission line (fig. 2–4) is to transfer the EMF energy from the transmitter to the antenna with minimal signal loss. Lower frequency sources use cables, such as the parallel pair line type which link antennas with old television sets, and the coaxial line, roughly similar to those used for cable TV connections. As the frequency increases, more shielding is needed to prevent power losses. The line can radiate most of the EMF radiation at higher frequencies before the energy can get to the antenna. In effect, the line itself becomes an unwanted antenna. The term "unwanted" is used because EMF radiation emitted in this manner cannot be controlled or directed as it can with a real antenna.

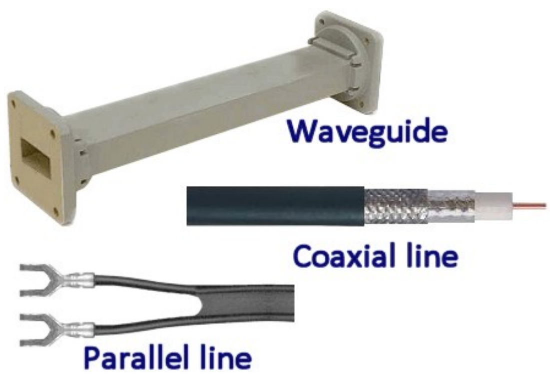

Figure 2–4. Transmission line examples.

Although coaxial cables are sometimes used for frequencies of 26 GHz and higher, normally a waveguide is used to transfer frequencies above 3,000 MHz with minimal energy losses. The waveguide is a circular or rectangular hollow metal pipe that conducts EMF radiation by allowing it to reflect off the inner sides of the pipe. This reflection can only occur when the widest dimension of the waveguide interior (cross-section) is at least one-half the wavelength of the frequency being used (fig. 2–5).

For example, an operating frequency of 3,000 MHz has a wavelength of 10 centimeters (cm), or about four inches. The waveguide would need to have one dimension that is at least 5 cm to work with a 3,000 MHz frequency. Waveguides are not normally used at LFs—they would have to be inconveniently large to allow the associated long wavelengths to fit. There are, however, some LF types used for test and calibration purposes that are large enough for a person to walk into. The wavelength is also important in cases of leaky or broken waveguides. If the largest dimension of a break is less than one-half wavelength, it will not leak; however, it will if the dimension exceeds one-half the wavelength.

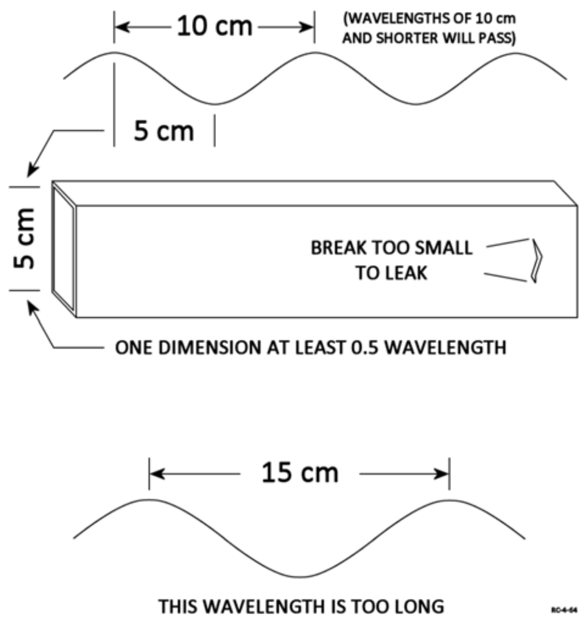

Figure 2–5. Relationship of wavelength to waveguide size.

Antenna

The antenna is the primary concern of health risk assessors. This is because the antenna is the point at which EMF energy is intentionally emitted to free space, thereby, making personnel exposure possible. The characteristics of the antenna determine the shape of the EMF radiation field or beam and thus how directional (concentrated in one direction) the beam is. The variety of antenna types and shapes is staggering; many may not even appear to be antennas. Regardless of the type, gain and power density are the properties important to the bioenvironmental engineer.

Gain is a measure of how well an antenna controls the direction the radio waves travel from the antenna. A simple pole antenna transmits in all directions, giving it a gain of 1. If some type of reflector is used, such as a satellite dish, the radio waves are focused, and the gain is increased. The power density is the strength of the radiation field at a specific location and distance from the antenna. As shown in figure 2–6, power density is the power output of the transmitter spread over the radiation field and is, thus, diluted by distance. The power must cover ever-greater areas as it travels outward. One way to think of this is how a flashlight works in relationship to distance. If a flashlight is pointed towards something near, it will effectively highlight the area. If the same flashlight is pointed towards something farther away, the object will not be as brightly lit. The unit used to express transmitter power is watts. The power transmits through an area or onto a surface area, expressed in square meters (m^2). Therefore, the units W/m^2 or mW/cm^2 are used for expressing power density. When gain is increased, it also has an impact on the power density similar to focusing a flashlight. The absolute gain is a ratio of the power density of the radio waves compared to the density they would be if the gain were 1. Absolute gain is important when determining hazard distances from antennas.

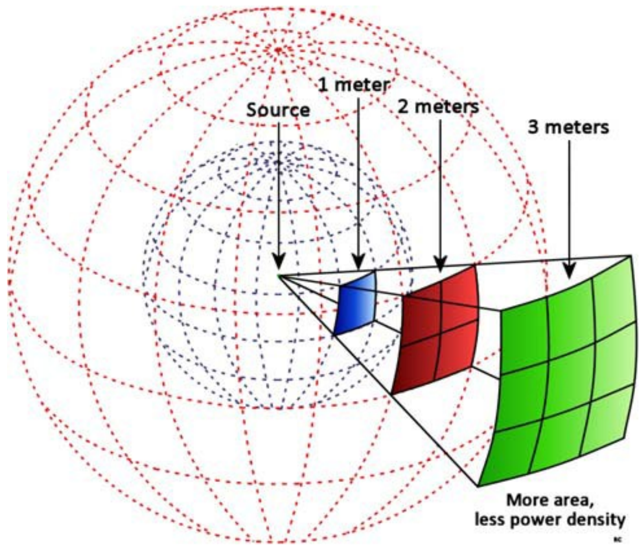

Figure 2–6. Power density decreases as distance increases.

Figure 2–6 demonstrates that power density is reduced to one-fourth at twice the distance from its source and one-ninth at three times the distance. This is a visual representation of the inverse square law. Any point source that spreads its influence equally in all directions without a limit to its range will obey the inverse square law. EMF radiation is no exception to this rule, as long as there are no overlapping fields from other antennas and the point of interest is far enough from the source to be in the region referred to as the far field (Fraunhofer region).

As EM energy is transmitted, it travels through two basic fields (fig. 2–7):

- Near field: Composed of the reactive and radiative regions. The electric and magnetic fields in these regions are very complex, which makes it difficult to predict the power density. Measurements in this area must be taken with great care, by very knowledgeable personnel.
- Far field: Generally begins approximately two wavelengths from the antenna. The electric and magnetic fields propagate at 90° angles and the power density is more predictable. For this reason, most measurements are taken in this region.

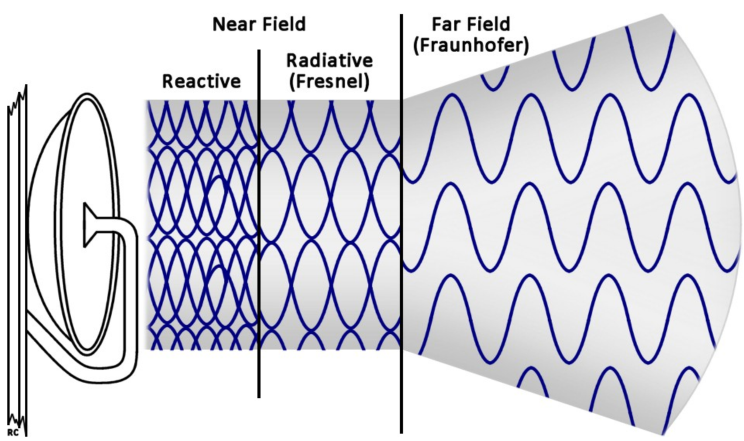

Figure 2–7. Near field and Far field EMF regions.

Antennas come in many different shapes and sizes, which can make them challenging to identify. Almost anything from a small stubby fin on an aircraft to a gigantic array of wires can act as an antenna; so, it’s important to identify their presence on or around an installation. Figure 2–8 shows a number of different types, ranging from the most common, monopoles (used on two-way radios) and dipoles, to the more unusual-looking types. Some types, like the Yagi and log periodic (similar to those used for television reception) are simply arrays of dipoles arranged for directionality and in different lengths to respond to different frequencies.

A reflector can operate effectively even with holes over its surface, as long as the holes are much smaller than one wavelength. This type of common antenna dish is no more than a screen, grid, or system of metal bars. The reflecting surface appears smooth and continuous to long wavelengths. Note the size of the holes in the screen imbedded in a microwave oven door window; it is designed to be a reflecting surface. Microwave ovens operate around 2,450 MHz, giving them a wavelength of about 12 cm (5 in), but the holes are much smaller. This design prevents microwaves from escaping thus allowing the user to safely view inside the microwave oven.

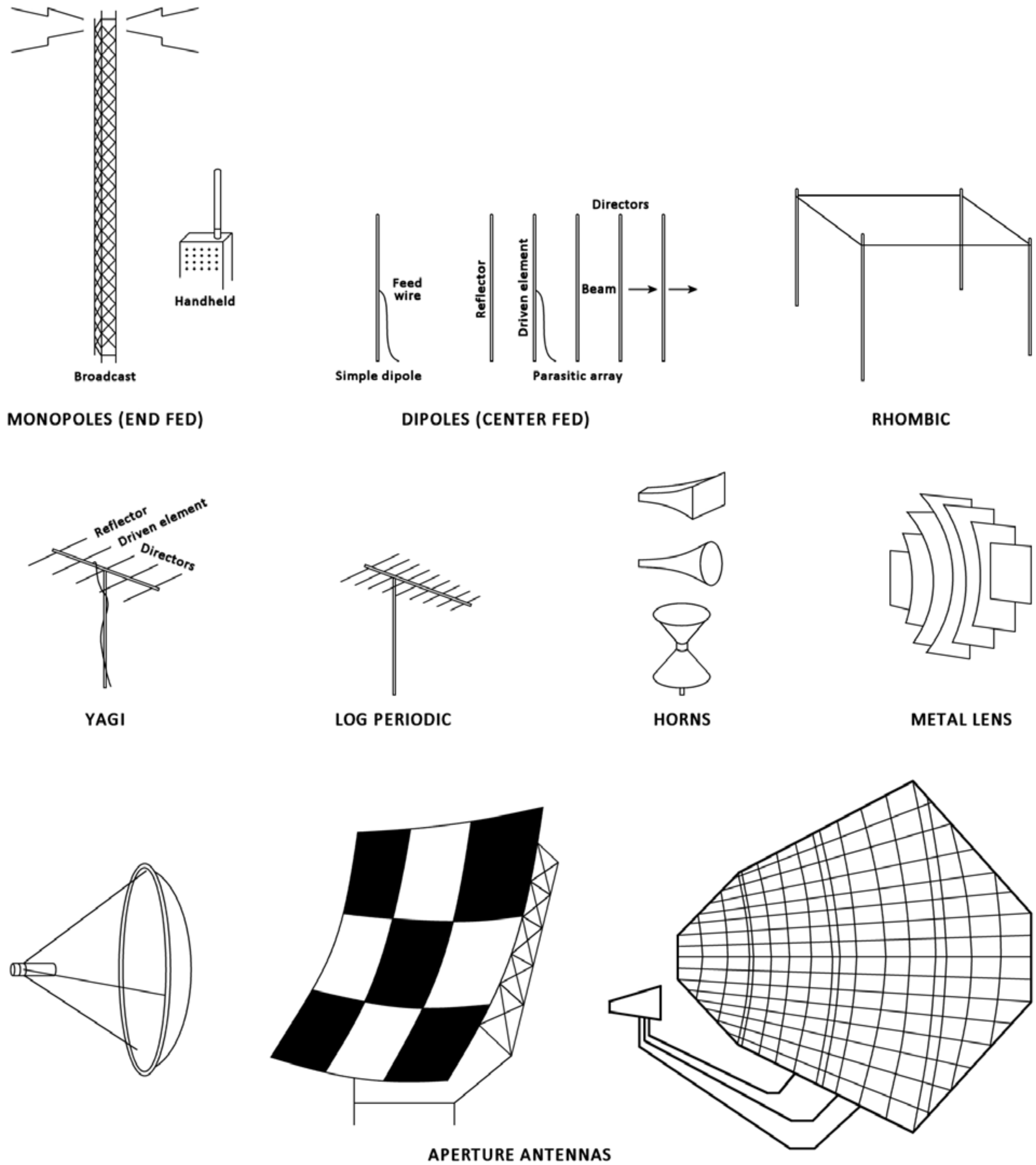

Figure 2–8. Antenna types.

Although transmission is a concern with antennas, they can also receive signals. The reflector that sends EMF radiation out into the atmosphere is often used to gather incoming signals, whether from another transmitter or the echoes of its own transmissions (the radar principle). The importance of this to the bioenvironmental engineer (BEE) is that the human body can absorb EMF radiation and unknowingly act as a receiving antenna in many EMF fields.

The *parameters* used to describe the operational and functional capabilities to transmit EMF radiation signals are:

- Frequency.
- Transmitter type.
  - Continuous wave.
  - Pulsed wave.
- Peak power.
- Gain.
- Beam width.

These parameters can be utilized to define the output of a given system and identify potentially hazardous areas. The parameters vary for each type of system. Fortunately, most emitters on a typical base have well-defined parameters. In most situations, emitters are constructed and operated in standardized configurations. As such, they are used throughout the Air Force with little change to their operational and hazard parameters. The United States Air Force School of Aerospace Medicine (USAFSAM) maintains much of the critical data needed to determine the hazards of standard emitters. This information is available through the Defense Occupational and Environmental Health Readiness System (DOEHRS). Some of the parameters needed to perform a survey correctly and safely are properties of the emitter, while other parameters are calculated values that are derived from other (known) parameters.

Frequency

All EMF radiation emitters are referred to by the frequency at which they operate. For instance, a radio station tuner may say 104.5, 99.5, or 97.3—those are all radio frequencies. What it does not say is the unit of measurement for those frequencies, which would be MHz for FM stations and kHz for AM stations. The radio station’s towers (antennas) transmit on those frequencies. Emitters on an AF base operate at specific frequencies as well.

Frequency is one of the most important parameters of radiation emitters because of the hazard potential to humans. For example, the human body is most susceptible to frequencies between 40 and 70 MHz. As the frequency increases, individual organs become more susceptible. This explains why EMF exposure limits are a function of frequency.

Transmitters

The transmitters of an EMF system will operate in one of two modes: continuous wave or pulsed wave (fig. 2–9).

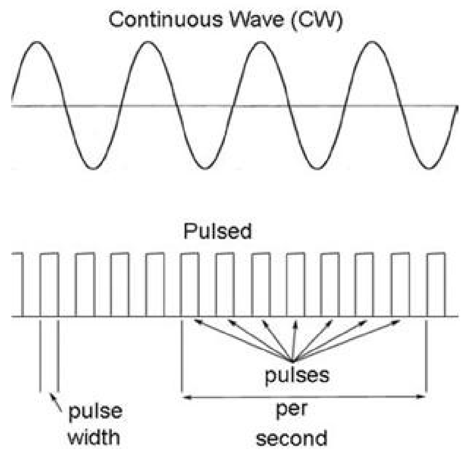

Figure 2–9. Continuous wave versus pulsed wave.

Continuous wave systems

The signal is always being emitted in a continuous wave system. For example, when a light is turned on, a continuous flow of electricity flows to the bulb. Continuous wave systems are required for uninterrupted communications such as radio or television broadcasting.

Pulsed wave systems

The signal in a pulsed wave system is intermittent (it turns on and off in a very rapid sequence). The pulsing technique allows the unit to send out a signal and then shut off momentarily to "listen" for an echo (reflection). This type of transmitter is commonly used in radar systems.

To properly assess a pulsed wave system, one must know how much time the EMF is emitted. The pulse width (PW***)*** is the length of time each pulse lasts, usually microseconds (µsec). The pulse repetition frequency (PRF) is the number of pulses per second in a pulsed wave emitter system.

Peak power

The peak power (P_p) is the highest power output given by an emitter while it is on and usually measures in kW or megawatts (MW). The average power of a pulsed transmitter depends upon how long each pulse lasts and how many pulses there are each second. The average power is used for health risk assessments of pulsed wave systems. For continuous wave systems, the peak power and the average power are the same since they run continuously when turned on.

Gain

Gain (measured in dB) is also known as directivity, which is a property of the antenna's ability to concentrate (or direct) its energy in a certain direction. It is a measure of how directional a radiation field is compared to the field of an omnidirectional (radiation sent out in all directions), or more appropriately, isotropic antenna. As shown in figure 2–10, a hypothetical isotropic antenna will have a radiation field pattern of an expanding sphere (with the antenna in the center), and the gain will be one. However, there is no such thing as a truly isotropic antenna, so the gain of a real antenna must always be greater than one. If the power is concentrated in one-half of the original area, the gain is two; if power is concentrated in one-fourth of the area, the gain is four, and so forth. The common dipole antenna, which consists of a wire or metal tube with energy fed at its center, is considered isotropic for practical purposes. This type has a gain between one and four in its simplest configurations. As a rule of thumb, the higher the gain, the narrower the beam and the more concentrated the energy. Knowing whether the beam is narrow or wide will help the assessor locate the energy in order to measure it for a health risk assessment.

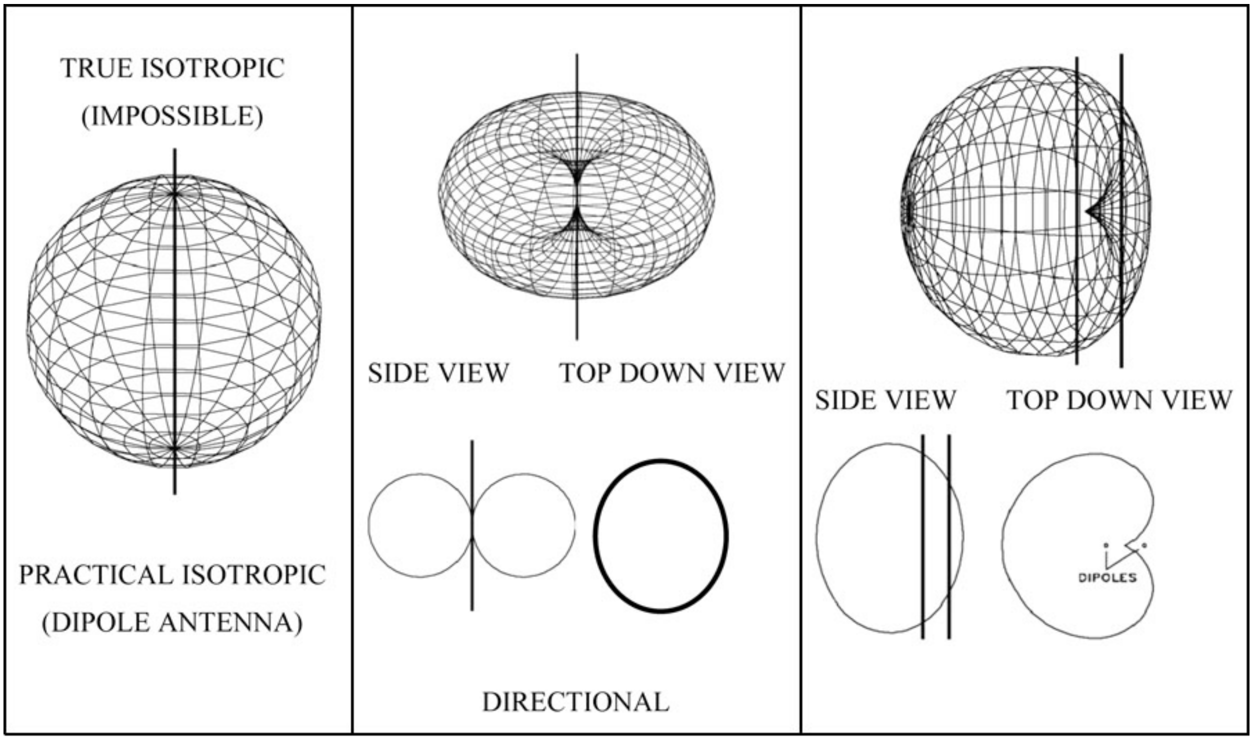

Figure 2–10. Antenna gain directivity patterns.

Beam width

If the antenna is scanning, exposure levels can be further reduced by considering the amount of time the beam is actually pointed toward an area. The rotational reduction factor (RRF) pertains to rotating or scanning systems only. It is the percentage of time the EMF radiation illuminates a given point, with respect to the total time the system is on. The RRF is a function of the beam width and the sector size.

Beam width is a property of high gain emitters and is the measure of the width of the beam in degrees. The beam width may be listed vertical, horizontal, or both. If there are both vertical and horizontal beam widths (with different values), use the vertical beam width value if the antenna motion is up and down. If the antenna sweeps back and forth or rotates horizontally, use the horizontal beam width value.

The sector size is the sweep path of the beam in degrees, such as 360 degrees for a rotating antenna, and 180 degrees for an antenna that rotates only half a circle and back. The sector size may be much smaller for a vertical scan, where it may only scan in a 45-degree vertical motion. Since the exposure time for scanning systems is typically very short, the potential for overexposure is usually small.

606. Types of electromagnetic frequency radiation emitters

Based on the characteristics and intended use, distinctions can be made about EMF radiation emitters. Communications equipment is the most widespread source of EMF radiation. Such equipment ranges from small emitters, such as handheld two-way radios, to huge antennas and powerful transmitters for long-range communications. Satellites, radio and television broadcasting, and general voice or coded communications also fit in this category. Each category and application are assigned a distinct frequency range to help keep one signal from interfering with another.

In the military, distinctions among emitters are made according to their uses. An alpha-numeric nomenclature is assigned to identify the type and use for all emitters within the USAF. The Table of -1 Equipment Indicator Letters can be used to find out this information by matching the three capital letters of the equipment designation to the three table columns. For instance, the first three letters of the designation FRC–170 show that F indicates “fixed ground” (first column), R stands for “radio” (second column), and C means “communications” (third column). Another example, the ARC–186, indicates “piloted aircraft radio used for communications.” Often the emitter indicator letters are prefixed with a service indicator “AN/” which means Army-Navy, but it includes Air Force equipment as well.

–1 EQUIPMENT INDICATOR LETTERS		
Type of Installation	**Type of Equipment**	**Purpose of Equipment**
A – Piloted aircraft	A – Invisible light, heat radiation	A – Auxiliary assemblies (not complete operating sets used with or part of two or more sets or sets series)
B – Underwater mobile, submarine	B – Pigeon	B – Bombing
C – Air transportable (inactivated)	C – Carrier	C – Communications (receiving and transmitting)
D – Pilotless carrier	D – Radiac	D – Direction finder, reconnaissance, and/or surveillance
F – Fixed ground	E – Nupac	E – Ejection and/or release
G – General ground use	F – Photographic	G – Fire control and searchlight directing
K – Amphibious	G – Telegraph or teletype	H – Recording and/or reproducing (graphic meteorological and sound)
M – Ground, mobile	I – Interphone and public address	K – Computing
P – Portable	J – Electromechanical or inertial wire covered	L – Searchlight control (inactivated)
S – Water surface	K – Telemetering	M – Maintenance and/or test assemblies (including tools)
T – Ground, transportable	L – Countermeasures	N – Navigational aids (including altimeters, beacons, depth, sounding approach, and landing)
U – General utility	M – Meteorological	P – Reproducing (inactivated)
V – Ground, vehicular	N – Sound in air	Q – Special or combination of purposes
W – Water surface and underwater	P – Radar	R – Receiving, passive detecting
Z – Piloted and pilotless airborne vehicle combination	Q – Sonar and underwater sound	S – Detecting and/or range and bearing, search
	R – Radio	T– Transmitting
	S – Special types, magnetic, etc., or combinations of types	W – Automatic flight or remote control
	T – Telephone (wire)	X – Identification and recognition
	V – Visual and visible light	
	W – Armament (peculiar to armament, not otherwise covered)	
	X – Facsimile or television	
	Y – Data processing	

Navigational radar, such as the AN/GPN–22 (skip over the “AN” to “GPN”—i.e., general ground-based radar used for navigation) is also a widely used EMF radiation application. It finds use, both onboard aircraft and on the ground, to guide aircraft to their destinations. There are different types of navigational radar including instrument landing systems (ILS), precision approach radar (PAR), tactical air navigation (TACAN), and VHF omnidirectional range (VOR). Do not confuse these abbreviations with the equipment designations in the above table.

NOTE: Most radar operates in the microwave region of the EMF spectrum.

The USAF uses many types of emitters to support its mission. Some of the more powerful are electronic countermeasures (ECM) and fire control. The ECM emitter, such as the ALQ–131, is a type of airborne, or sometimes, ground-based radar unit. It is designed to emit signals that disrupt the effective use of a portion of the EM spectrum. A communications jammer, for instance, makes it more difficult if not impossible, to communicate on the frequencies being jammed. A radar jammer on a fighter or a bomber plane can make it more difficult to zero in on and shoot down an aircraft. Weapons fire control, like the APG–63, is used to track targets and direct missiles, shells, or bombs. There are countless uses for EMF emitters; a short list of other high-powered emitters includes:

- FPS–115 (Pave Paws): An early attack warning radar.
- APN–59: Used for weather detection/avoidance.
- APM–427: Test assemblies used in some shops.

EMF emitters are not just found on aircraft. The USAF also has industrial (such as heat sealers and microwave ovens) and medical (like diathermy used in physical therapy) applications. BE must always be aware of new emitters brought onto installations. These emitters must be evaluated for the potential hazards they create; but to determine health risk, there must be an understanding of how EMF radiation affects the body.

607. Health risks of electromagnetic frequency radiation exposure

Energy from the EMF field is transferred to human tissue by exciting the water molecules in the tissue. Changes result from the absorption of energy which may, or may not, produce temperature increases. The absorption of EMF energy by biological materials is strongly influenced by the emitted frequency and the orientation of the object in the EM field. Similar to antennas, the body size (or body organ size), when compared to the wavelength, is generally the most critical factor concerning the absorption of EMF radiation. Looking at this relationship between wavelength and body size, it is found that generally, the body size must be at least one-tenth of the wavelength for any significant effect to occur. Below 10 MHz (wavelengths of 30 meters (m) or 3,000 cm) the body is transparent to EMF radiation (i.e., the radiation passes through the body without being absorbed). As the frequency increases, the body becomes larger in relation to the wavelength, and more energy is absorbed. In most cases, optimal absorption occurs at frequencies of about 70-80 MHz. Generally, increases in frequency result in increased absorption in individual body organs. At frequencies above 10,000 MHz (wavelengths of 3 cm), the skin surface is the absorber, and deeper penetration does not take place. While uncommon, a person’s body that is electrically grounded can cause the EMF radiation wave reflecting off the ground plane to appear twice as long. The significance here is that peak absorption takes place at about 35 to 40 MHz.

Direct biological effects

Thermal effects are the result of sufficiently high levels of EMF radiation energy that cause heating in body tissues. Tissues with high water content (skin, muscle, and internal organs) absorb much more energy than those with low water content (such as bones). Absorption by the skin often gives adequate warning of danger, because a person can feel the heat. However, deeper tissues do not have the heat sensors of the skin, and damage can occur before a victim feels anything. The most sensitive organs are those with lower blood flow, such as the eyes, testicles, gall bladder, and urinary bladder. They are not able to dissipate heat buildup as efficiently and can be damaged severely before a person realizes they are injured.

An EMF radiation induced thermal burden produces normal physiological responses like sweating and dilated blood vessels. If the heat is not dissipated effectively, the exposed tissue will be heated and possibly damaged. The effects of this type of exposure are not considered to be cumulative, as they are with ionizing radiation.

The “microwave hearing effect” has been known for more than three decades and consists of an audible sound which seems to originate within or near the head. The sensation is described as a clicking, buzzing, or chirping sound depending upon the pulse repetition rate and pulse width of the incident EMF radiation. It is suspected that the inner ear picks up pressure waves produced by EMF energy in a manner that is similar to the way ordinary sound waves are perceived. This effect, of itself, is not considered to be hazardous. However, any reports of this effect should be investigated because it can indicate a possible overexposure.

Research continues into athermal effects: biological effects that are not associated with thermal absorption. Research suggests connections to nervous system effects and leukemia; however, the data is inconclusive. Not enough data has been collected to establish a set of standards based upon observed athermal effects. Therefore, the current USAF standard for EMF radiation protection is designed to protect personnel from known thermal hazards associated with EMF radiation.

Indirect effects

In addition to direct biological effects, indirect effects from EMF radiation acting on other mediums are also a significant concern. Some indirect effects include:

- Interference with electronics (especially biomedical life-support equipment).
- Ignition of petroleum products.
- Detonation of electro-explosive devices in some munitions.
- High voltage hazards.
- Ionizing x-ray radiation generated from high-powered RADAR systems.
- Electric current that is either induced or flows through contact.

An induced current is an electric current that flows through the body induced by the low frequency high power EMF radiation field surrounding the body. In comparison, contact current is the electric current flow through the body as the result of physically touching a portion of the body and a component of a low frequency, high power EMF emitter. Evaluation of induced EMF currents will generally require a measurement unless the exposure situation is very simple. Many exposure conditions are complex and induced current exposures are difficult to evaluate. Consult with USAFSAM to determine the potential for exceeding these current limits.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

605. Principles of electromagnetic frequency radiation

1. What frequencies encompass the EMF spectrum?

2. EMF uses what range of wavelength?

3. What are the basic components of any EMF system?

4. What is a waveguide?

5. In what two modes do EMF transmitters operate?

6. What property of the antenna allows it to concentrate its energy in a certain direction?

606. Types of electromagnetic frequency radiation emitters

1. What type of EMF emitter has the designation BQN?

2. Where on the EMF spectrum does most radar operate?

607. Health risks of electromagnetic frequency radiation exposure

1. Hearing a clicking sound is an example of what biological effect?

2. Interference with electronics is an example of what type of EMF effect?

2–2. Measuring Electromagnetic Frequency Radiation and Assessing Risk

The risk assessment process involves identifying and analyzing the potential risk to human health. This section addresses the methodology for identifying EMF hazards and analyzing the associated risk as described in AFI 48-109, *Electromagnetic Field Radiation (EMFR) Occupational and Environmental Health Program*.

608. Performing electromagnetic frequency radiation risk assessments

Fortunately, most EMF radiation emitters on a typical base have well-defined parameters and technical orders with good procedures that minimize exposure. However, there's still the potential for error or mishaps to occur during routine operations. Knowing where these emitters are used, their hazard potential, and the personnel at risk of exposure is critical to good health risk assessments and risk management. Evaluations are based on power densities produced by the emitter and accessibility to personnel.

The evaluation requirements for an EMF emitter can be summarized in six steps:

1. Identify EMF radiation sources.
2. Determine emitter hazard potential.
3. Determine the applicable exposure limit for each emitter.
4. Estimate the hazard distance.
5. Perform a site inspection.
6. Measure to identify actual hazard locations and to define controls.

Step 1: Identify electromagnetic frequency radiation sources

Due to the long history of AF use, most BE flights have established comprehensive EMF inventories. The EMF inventory includes much of the following:

- List of emitters.
- Emitter locations.
- Emitter parameters.
- Estimated hazard distance(s).
- Measured hazard distance(s) (if emitter can exceed the exposure limit).

NOTE: The term “hazard distance” refers to the distance from the antenna to the point at which the maximum permissible exposure (MPE) limit is found.

The EMF inventory is a very good starting point to find if all emitters on the base have been identified. The base frequency manager is also a good point of contact to verify if all EMF emitters are on the inventory. This individual, who is usually assigned to the communications squadron, has a list of all frequencies authorized for use on base (except airborne emitters) and can provide a list of emitters and their general locations. Once the search has been narrowed to the unit level, individual unit supervisors should be able to help find exact locations and usage. Another valuable asset to BE is the installation safety engineer. The safety engineer can assist with identifying emitters on base and communicating key components of the EMF program safety requirements to workplace supervisors.

The exact operating frequency for some emitters is classified, but the exact frequency is not always needed to determine the proper MPE and to select the appropriate survey probe. In these cases, use a range of frequencies (enough to determine the MPE and select the correct instrument probe). It is important to not inadvertently capture classified information in documentation. Since the specific frequency will remain classified, state “masked for security reasons” while documenting the risk assessment. During site reconnaissance, verify the emitter inventory information and be observant of new, removed, or changed emitters.

Step 2: Determine emitter hazard potential

Each emitter may be classified according to its hazard potential. The major factors in determining the hazard potential of a particular emitter are based on the emitter’s power and accessibility to the emitter by personnel. Assign each emitter one or more of the following categories in DOEHRS:

Non-hazardous emitters

Low-power devices (as defined by AFI 48-109) not capable of producing power density levels at or above the MPE. Commercially procured telecommunications systems designed for public use (e.g., cellular phones, Wi-Fi networks) and medical treatment devices that are used in their manufactured condition do not require a special evaluation beyond manufacturer recommendations.

Ground-level hazard emitters

Systems capable of producing power density levels at or above the MPE in areas accessible to personnel at or near ground level. This can generally be determined by the location of the main beam above ground level, the size and shape of the beam, and the angle of elevation. Many aircraft mounted radar and ECM systems are included in this category. These types of systems should be the highest priority during the evaluation phase.

Climbing hazard emitters

Systems capable of producing power density levels in excess of the MPE but only in areas that require climbing. These emitters should be evaluated to determine if, when, and where maintenance personnel may be required to climb into these areas. Even if the maintenance procedures require shutdown with manual or automatic interlocks, the potential for exposure may still exist if the controls are bypassed or have failed. Exposure levels where the public may have access to the main beam should be calculated and compared to the MPEs to determine compliance. These systems should be the second priority on the list of systems that require further evaluation.

Inaccessible emitters

Systems capable of producing power density levels in excess of the MPE but are not accessible to personnel. These systems should be evaluated to determine if maintenance procedures require entry into areas where the MPE could be exceeded. Those areas where maintenance is performed should be included at least initially, and annually thereafter. These types of systems should be the third priority on the list of systems that require further evaluation.

Short duration emitters

Systems capable of producing power density levels in excess of the MPE, but under normal operating conditions the transmission time is shorter than the MPE averaging time. The transmission time is usually too short to result in an exposure likely to produce a specific absorption rate (SAR) greater than 0.4 watts per kilogram (W/kg). These types of systems may include portable radios, base stations, some airborne and ground communications systems that require manual or voice activation, and so forth, to transmit. Some automatic systems will transmit just long enough to retransmit a message. Beam on-time could vary but is not likely to exceed the duration necessary to result in an overexposure. Repair and maintenance workplaces where these systems are maintained should be a higher priority than routine operations when evaluating these types of systems.

Step 3: Determine the applicable exposure limit for each emitter

The MPE is not a specific quantity like those found for chemical exposures. This exposure limit is dependent on several factors, including frequency, exposure time, and type of environment and must be calculated, which will be shown later.

Step 4: Estimate the hazard distance

Theoretical hazard calculations are useful for predicting the distance at which the MPE is expected to be exceeded relative to the radiating element or antenna. The hazard distance is the distance from the antenna to the farthest point where exposure rates exceed the MPE. Theoretical hazard evaluations will provide the surveyor with a safe distance from which to approach the antenna. This distance is affected by the MPE calculation, and is, therefore, determined after the MPE has been determined.

Step 5: Perform a site inspection

An inspection of the emitter site should determine if it is accessible to personnel and if power density measurements are required. Personnel should notify BE and installation ground safety personnel upon occurrence of any suspected personnel exposure, radiation leakage, or changes in existing systems/operating conditions. During the site inspection, it is important to verify any conclusions drawn during the recognition phase.

Step 6: Measure to identify actual hazard locations and to define controls

Finally, if necessary, the site must be surveyed, measurements taken, and controls determined. Onsite measurement surveys must be conducted in all cases where there is any doubt about where personnel hazards (power densities at or above the MPE) might exist.

609. Determining electromagnetic frequency radiation permissible exposure limits

Maximum permissible exposures associate the EMF radiation field to the energy absorbed in a human body with the related health effects it may cause. The term used to describe the absorbed energy is these. This is the rate (in seconds) at which EMF radiation energy (in joules) is imparted to an element of biological mass (kilograms). Joules per second is equivalent to watts; therefore, SAR can be expressed in units of W/kg.

Studies have shown that the threshold for potential health effects from whole body exposure to EMF is a SAR of 4.0 W/kg. Maximum permissible exposures are based on a SAR of 0.4 W/kg, a safety margin which is a factor of ten below the health effect threshold (fig. 2–11).

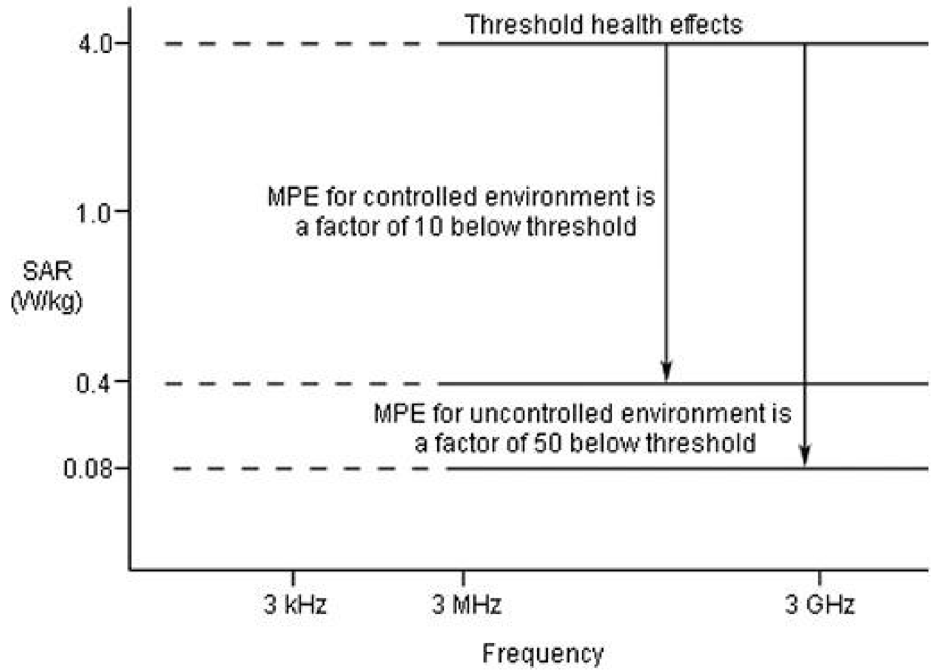

Figure 2–11. SAR Health Effect Thresholds.

In AFI 48-109 the AF adopted the EMF radiation MPEs developed by representatives of industry, scientific communities, government agencies, and the public published in American National Standards Institute/Institute of Electrical and Electronics Engineers (ANSI/IEEE) STD C95.1. These MPEs incorporate the SAR described above. Figures 2–12 and 2–13 are MPE charts listed in AFI 48-109. Typical EMF radiation measurements BE personnel collect provide results in terms of power density (W/m^2 or mW/cm^2) instead of E field (V/m) or H field (A/m). By knowing the frequency (or determining the worst-case frequency), one can use the fourth column of the table (power density) for comparison to the MPE.

Remember that the SAR units of W/kg indicate the energy absorbed in a body mass over a period of time. By averaging the overall energy received over time from the EMF radiation field (calculating variances due to pulse, scanning, and phasing) exposures can be compared to the SAR. The “averaging time” column in the MPE tables introduces the concept of averaging periods of six minutes, 30 minutes, or time based on calculations related to frequency. These times reflect the body’s ability to dissipate the energy by cooling itself at the various frequencies. This implies that a trained worker could remain in an EMF radiation field as long as the average exposure during any averaging period does not exceed the MPE regardless of how long the worker has been in the field or when the count for averaging time began.

For exposure duration less than the averaging period, the maximum permissible exposure level is MPE [Tavg/Texp]; where Texp is the exposure duration in that interval expressed in the same time units as Tavg.

Note that there are two different sets of MPE tables; one for environments where workers have been trained and understand the hazards of exposure (upper tier), and another for members of the general population who have no knowledge or control over the exposure (lower tier).

The upper tier applies to exposure of persons in controlled environments. The lower tier, with an additional safety factor, recognizes public concerns and also supports the process of harmonization with other standards, for example, the National Council on Radiation Protection and Measurements recommendations and the International Commission on Non-Ionizing Radiation Protection guidelines (uncontrolled environments). The lower tier also defines the action level above which implementation of an EMF safety program is recommended. The MPEs of the lower tier may also be used for the general public to address concerns of continuous, long-term exposure of all individuals.

Upper tier environment: Locations where EMF exposures do not exceed the MPEs in figure 2–12 (AFI 48-109, Table A2.1) but may exceed the MPEs in figure 2–13 (AFI 48–109, Table A2.2). Upper tier environments represent areas that may be occupied by personnel who accept potential exposure as a term of employment or duties, by individuals who knowingly enter areas where such levels are to be expected, or by personnel passing through such areas.

Upper tier environments may be established using existing physical arrangements or areas, such as fences, perimeters, or weather decks of a ship. The upper tier MPEs were developed to reduce human exposures to electromagnetic energy at frequencies ranging from 0 kHz-300 GHz, and to limit the localized SAR occurring in the feet, ankles, wrists, and hands of personnel due to exposure to such fields or contact with objects exposed to such fields.

While the weight of scientific evidence supports the conclusion that there is no measurable risk associated with EMF exposures below the upper tier of this standard, it is scientifically impossible to prove absolute safety (the null hypothesis) of any physical agent.

Lower tier environments: Locations where EMF exposures do not exceed the MPEs in figure 2–13 (AFI 48–109, Table A2.2). Lower tier environments generally represent living quarters, workplaces, or public access areas where personnel would not expect to encounter higher levels of EMF energy.

Action Level: The USAFSAM *Base-Level Guide for Electromagnetic Frequency Radiation* (AFRL–SA–WP–SR–2013–0003) requires that any exposures in excess of those indicated in figure 2–13 (AFI 48–109, Table A2.2) shall require the adoption of an EMF safety program. Where installations have emitters that can create power densities above the action level/lower tier MPE; then, a safety program must be adopted.

Table A2.1. MPEs for the Upper Tier.

A. MPE for Upper Tier

Frequency Range (f) (MHz)	Electric Field - rms (E)[a] (V/m)	Magnetic field strength - rms (H)[a] (A/m)	Power Density - rms (S) E-field, H-field (W/m^2)	Averaging time $\|E\|^2$, $\|H\|^2$ or S (min)
0.1 - 1.0	1842	$16.3/f_M$	$(9000, 100\,000/f_M^2)$[b]	6
1.0 – 30	1842/f	$16.3/f_M$	$(9000/f_M^2, 100\,000/f_M^2)$	6
30 – 100	61.4	$16.3/f_M$	$(10, 100\,000/f_M^2)$	6
100 – 300	61.4	0.163	10	6
300 – 3000			$f_M/30$	6
3000 – 30 000			100	$19.63/f_G^{1.079}$
30 000 – 300 000			100	$2.524/f_G^{0.476}$

NOTE: f_M is the frequency in MHz, f_G is the frequency in GHz

[a]For exposures that are uniform over the dimensions of the body, such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the MPEs in section A of this table. For non-uniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the squares of the field strengths or averaging the power densities over an area equivalent to the vertical cross section of the human body (projected area), or a smaller area depending on the frequency, are compared with the MPEs in section A of this table.

[b]These plane-wave equivalent power density values are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

B. Electric field MPE: whole body exposure:
F= 3 kHz to 100 kHz

Frequency range (kHz)	E (rms) (V/m)
3 – 100	1842

C. MPE for exposure of head and torso:
F= 3 kHz to 5 MHz

Frequency range (kHz)	Flux Density B_{rms} (mT)	H_{rms} (A/m)
3.0 – 3.35	2.06/f	1640/f
3.35 – 5000	0.615	490

NOTE—f is expressed in kHz.

D. MPE for limbs:
3 kHz to 5 MHz

Frequency range (kHz)	B_{rms} (mT)	H_{rms} (A/m)

3.0 – 3.35	3.79/f	3016/f
3.35 - 5000	1.13	900
NOTE: f is expressed in kHz.		

E. RMS induced and contact current limits for continuous sinusoidal waveforms 3 kHz to 100 kHz

Condition	Persons in Upper Tier environments (mA)
Both feet	2.00f
Each foot	1.00f
Contact, grasp[b]	1.00f
Contact, touch	0.50f

NOTE 1: f is expressed in kHz.

NOTE 2: Limits apply to current flowing between the body and a grounded object that may be contacted by the person.

NOTE 3:The averaging time for determination of compliance is 0.2 s.

[b]The grasping contact limit pertains to Upper Tier environments where personnel are trained to make grasping contact and to avoid touch contacts with conductive objects that present the possibility of painful contact.

F. RMS induced and contact current limits for continuous sinusoidal waveforms F=100 kHz to 110 MHz

Condition	Persons in Upper Tier Environments (mA)
Both feet	200
Each foot	100
Contact, grasp[b]	100
Contact, touch	50

NOTE 1: Limits apply to current flowing between the body and a grounded object that may be contacted by the person.

NOTE 2: The averaging time for determination of compliance is 6 minutes.

[b]The grasping contact limit pertains to Upper Tier environments where personnel are trained to make grasping contact and to avoid touch contacts with conductive objects that present the possibility of painful contact.

G. Basic restrictions applying to various regions of the body

Exposed tissue	f_e (Hz)	E_0 (rms) (V/m)
Brain	20	1.77×10^{-2}
Heart	167	0.943
Extremities	3350	2.10
Other tissue	3350	2.10

H. Basic restrictions for frequencies between 100 kHz and 3 GHz

		Persons in Upper Tier SAR[c] (W/kg)
Whole-body exposure	Whole-body average (WBA)	0.4
Localized exposure	Localized (peak spatial-average)	10[c]

	Extremities and pinnae	20[c]
[b]SAR is averaged over the appropriate averaging times as shown in section A of this table		
[c]Averaged over any 10 g of tissue (defined as a tissue volume in the shape of a cube)*		
[d]The extremities are the arms and legs distal from the elbows and knees, respectively		

I. Relaxation of the power density MPEs for localized exposures (partial-body exposure)		
Frequency Range (f) (MHz)	**Peak Value of Mean Squared Field**	**Equivalent Power Density (W/m^2)**
0.003 – 300	$<20\ E^2$ or $20\ H^2$ *	-
300 – 3000	-	200
3000 – 96 000	-	$200(f_G/3)^{1/5}$
f_M> 96 000	-	400
NOTE: f_M is the frequency in MHz, F_G is the frequency in GHz		
* E and H are the spatially averaged values from section A of this table		

J. Pulsed EMF Fields (apply only when there are < 5 pulses with the averaging time).		
Frequency Range (f) (MHz)	**Peak Electric Field (E) (kV/m)**	**Power Density Pulse for Pulse Durations < 100 msec (W/m^2)**
0.1 – 300 000	100	$(MPE)(T_{avg})/(5)$(pulse width)

K. Magnetic maximum permissible exposure (MPE) levels: exposure of head and torso [a, b]		
Frequency Range (Hz)	**Upper Tier environment**	
	B – rms (mT)	**H – rms (A/m)**
<0.153	353	$2.81x10^5$
0.153-20	54.3/f	$4.32x10^4/f$
20-759	2.71	$2.16x10^3$
759-3000	2060/f	$1.64x10^6/f$
[a] f is frequency in Hz [b] MPEs refer to spatial maximum		

L. Magnetic flux density maximum permissible exposure levels: exposure of arms or legs [a]	
Frequency Range (Hz)	**Upper Tier B – rms (mT)**
<10.7	353
10.7 - 3000	3790/f
[a] f is frequency in Hz	

Figure 2–12. AFI 48-109, Table A.2.1.

Table A2.2. MPEs for Lower Tier.

A. MPEs for Lower Tier

Frequency Range (f) (MHz)	rms electric field (E)[a] (V/m)	rms magnetic field strength (H)[a] (A/m)	rms power density (S) E-field, H-field (W/m^2)	Averaging time $\|E\|^2$, $\|H\|^2$ or S (min)	
0.1-1.34	614	$16.3/f_M$	$(1000, 100\ 000/f_M^2)$[c]	6	6
1.34–3	$823.8/f_M$	$16.3/f_M$	$(1800/f_M^2, 100\ 000/f_M^2)$	$f_M^2/0.3$	6
3–30	$823.8/f_M$	$16.3/f_M$	$(1800/f_M^2, 100\ 000/f_M^2)$	30	6
30–100	27.5	$158.3/f_M^{1.668}$	$(2, 9\ 400\ 000/f_M^{3.336})$	30	$0.0636\ f_M^{1.337}$
100–400	27.5	0.0729	2	30	30
400-2000	-	-	$f_M/200$	30	
2000-5000	-	-	10	30	
5000-30 000	-	-	10	$150/f_G$	
30 000-100 000	-	-	10	$25.24/f_G^{0.476}$	
100 000-300 000	-	-	$(90f_G-7000)/200$	$5048/[(9f_G-700)f_G^{0.476}]$	

NOTE: f_M is the frequency in MHz, F_G is the frequency in GHz

[a]For exposures that are uniform over the dimensions of the body, such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the MPEs in section A of this table. For non-uniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the squares of the field strengths or averaging the power densities over an area equivalent to the vertical cross section of the human body (projected area), or a smaller area depending on the frequency, are compared with the MPEs in section A of this table.

[c]These plane-wave equivalent power density values are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

B. Electric field MPE- whole body exposure:
3 kHz to 100 kHz

Frequency range (kHz)	E (rms) (V/m)
3 – 100	614

C. MPE for exposure of head and torso:
3 kHz to 5 MHz

Frequency range (kHz)	B_{rms} (mT)	H_{rms} (A/m)
3.0 – 3.35	0.687/f	547/f
3.35 – 5000	0.205	163

NOTE—f is expressed in kHz.

D. MPE for limbs:
3 kHz to 5 MHz

Frequency range (kHz)	B_{rms} (mT)	H_{rms} (A/m)
3.0 – 3.35	3.79/f	3016/f
3.35 - 5000	1.13	900
NOTE: If is expressed in kHz.		

E. RMS induced and contact current limits for continuous sinusoidal waveforms 3 kHz to 100 kHz

Condition	Persons in Lower Tier environments (mA)
Both feet	0.90f
Each foot	0.45f
Contact, grasp[b]	-
Contact, touch	0.167f
NOTE 1: f is expressed in kHz.	
NOTE 2: Limits apply to current flowing between the body and a grounded object that may be contacted by the person.	
NOTE 3:The averaging time for determination of compliance is 0.2 s.	

F. RMS induced and contact current limits for continuous sinusoidal waveforms 100 kHz to 110 MHz

Condition	Persons in Lower Tier Environments (mA)
Both feet	90
Each foot	45
Contact, grasp[b]	-
Contact, touch	16.7
NOTE 1: Limits apply to current flowing between the body and a grounded object that may be contacted by the person.	
NOTE 2: The averaging time for determination of compliance is 30 minutes.	

G. Basic restrictions applying to various regions of the body

Exposed tissue	f_e (Hz)	E_0 (rms) (V/m)
Brain	20	5.89×10^{-3}
Heart	167	0.943
Extremities	3350	2.10
Other tissue	3350	0.701

H. Basic restrictions for frequencies between 100 kHz and 3 GHz

		Persons in Lower Tier Environments SAR[c] (W/kg)
Whole-body exposure	**Whole-body average (WBA)**	**0.08**
Localized exposure	Localized (peak spatial-average)	2[c]

Localized exposure	Extremities[d] and pinnae	4[c]
[c]Averaged over any 10 g of tissue (defined as a tissue volume in the shape of a cube)*		

I. Relaxation of the power density MPEs for localized exposures (partial-body exposure)

Frequency Range (f) (MHz)	Peak Value of Mean Squared Field	Equivalent Power Density (W/m^2)
.003 – 400	$<20\ E^2$ or $20\ H^2$ *	-
400 – 3000	-	40
3000 – 30 000	-	$18.56(f_G)^{0.699}$
$f_M > 30\ 000$	-	200
NOTE- f_M is the frequency in MHz, f_G is the Frequency in GHz		
* E and H are the spatially averaged values from section A of this table		

J. Pulsed EMF Fields (apply only when there are less than 5 pulses with the averaging time).

Frequency Range (f) (MHz)	Peak Electric Field (E) (kV/m)	Power Density Pulse for Pulse Durations < 100 msec (W/m^2)
0.1 – 300 000	100	$(MPE)(T_{avg})/(5)$(pulse width)

K. Magnetic Maximum permissible exposure (MPE) levels: exposure of head and torso[a,b]

Frequency Range (Hz)	Lower Tier	
	B - rms (mT)	H – rms (A/m)
<0.153	118	$9.39x10^4$
0.153-20	18.1/f	$1.44x10^4/f$
20-759	0.904	719
759-3000	687/f	$5.47x10^5/f$
[a] f is frequency in Hz [b] MPEs refer to spatial maximum		

L. Magnetic flux density maximum permissible exposure levels: exposure of arms or legs [a]

Frequency Range (Hz)	Lower Tier B - rms (mT)
<10.7	353
10.7 - 3000	3790/f
[a] f is frequency in Hz	
NOTE: Measurements to determine adherence to the MPE shall be made at distances of at least 20 centimeters (cm) or greater from any object.	

Figure 2–13. AFI 48-109, Table A2.2.

The population exposed governs which set of MPEs (upper or lower tier) are required for determining exposure acceptability. Upper tier environment MPEs are selected for comparison to occupational EMF exposure among workers who are trained in EMF radiation hazards and commonly work with or around EMF emitters. Lower tier environment MPEs are selected for non-occupational EMF exposure or occupational EMF exposure among workers who do not normally work with EMF emitters and would not expect high EMF exposure. Once the population of interest is determined, the appropriate MPE can be evaluated. Often both must be considered to ensure each population is adequately protected.

For example, the commander wants to give the Squadron Spouses Club members a 15-minute tour of a communication array. The tour will expose members to an emitter that operates at 25 MHz. Previous measurements show the highest E field power density in the area measures 3.0 W/m^2. Could the MPE be exceeded?

The club members are not trained EMF radiation workers, so this is considered a lower tier environment. Using figure 2–13, the E field power density MPE is 1800/f^2 at 25 MHz or 2.9 W/m^2 (1800/25^2). At first, it may look like the exposure of 3.0 W/m^2 exceeds this MPE value; however, the averaging time must also be considered. The averaging time is 30 minutes for this frequency, so the shorter exposure time must be taken into account.

$$MPE_{adjusted} = MPE \text{ x } T_{ave} / T_{exp} = 2.9 \text{ W/m}^2 \text{ x } (30\text{min}/15\text{min}) = 5.8 \text{ W/m}^2$$

Taking the averaging time into account, the measured value of 3.0 W/m^2 is actually much less than the adjusted MPE of 5.8 W/m^2.

Once the MPE is determined, the next step (step 4) is calculating a hazard distance. An estimated hazard distance can often be obtained from equipment technical orders, USAFSAM reports, or manufacturer's specifications. These may, however, have additional factors of safety and, therefore, may not match calculated distances. This could become important when conducting a potential overexposure investigation.

610. Calculating hazard distances

The hazard distance (D_{MPE}) is the theoretical distance from the antenna to the location where the power density level is equal to the MPE." The emitter parameters are required in order to predict the hazard distance. Hazard distance calculations for some emitters are more complex than others, particularly with pulsed and scanning/rotating systems. For CW EMF radiation emitters, the calculation is straightforward. For more complicated systems, extra calculations may be needed to establish the average power and antenna gain correctly.

There are two similar calculations used, one for systems with stationary antennas and one for systems with rotating antennas. The discussion that follows introduces the formulas and addresses how each part is derived.

When surveying a system with a stationary antenna, use the following D_{MPE} calculation:

$$D_{MPE} = \sqrt{\frac{P_{ave} \times G_{abs}}{4\pi \times MPE}}$$

Where:
- D_{MPE} = hazard distance (in meters)
- P_{ave} = average power (in watts)
- G_{abs} = absolute gain (unitless)
- 4π = a constant related to diameter calculation and unit conversions
- MPE = maximum permissible exposure calculated in lesson 609 (in watts/meter^2)

Continuous wave: The peak power (P_p) is the average power (P_{ave}) for continuous wave emitters.

Pulsed waveform: For pulsed systems, the average power (in watts) is calculated by multiplying the peak power (in watts) by the duty factor (DF):

$$P_{ave} = P_p \times DF$$

Where:
- P_{ave} = average power (in watts)
- P_p = peak power (in watts)
- DF = duty factor (unitless)

The DF is a ratio of the total time, or total length of time EMF is emitted each second, determined by multiplying the PW by the PRF. The DF formula is only applicable to pulsed systems:

$$DF = PW \times PRF$$

Where:
DF = duty factor (unitless)
PW = pulse width (seconds)
PRF = pulse repetition frequency (pulses per second)

The absolute gain (G_{abs}) is calculated from the gain of the system and accounts for losses in the quality of the EMF radiation signal due to inherent system losses. Two formulas are used to calculate the absolute gain, dependent on the type of antenna being used.

Aperture antennas: The absolute gain for an aperture antenna is calculated as follows:

$$G_{abs} = \frac{4\pi A}{\lambda^2}$$

Where:
A = area of the aperture antenna ($meters^2$)
λ = signal wavelength (meters)

Non-aperture antennas: If the emitter has another type of antenna, besides an aperture antenna, the absolute gain is calculated as follows:

$$G_{abs} = 10^{\frac{Gain}{10}}$$

Where:
Gain = the antenna gain (dB)

Rotating antennas: If the system antenna is rotating, accurate measurements cannot be taken; therefore, the antenna must be put into a stationary mode to perform measurements. In some cases, stopping the antenna rotation engages the system interlocks and stops the EMF radiation signal. If the system cannot emit in a stationary position, it is best to perform a risk assessment based on calculated hazard distance with an RRF, rather than try to take measurements. The formula to calculate the RRF is shown below.

$$RRF = \frac{BeamWidth}{SectorSize}$$

Where:
RRF = rotational reduction factor (unitless)
Beam width = horizontal beam width (radians or degrees)
Sector size = extent of rotation (radians or degrees)

For example, if the horizontal beam width of the emitter is 1.1 degrees, and the emitter rotates in a full circle (360 degrees) the RRF = 1.1 ÷ 360 = 0.003.

When assessing a system with a rotating antenna, RRF is added to account for reduced exposure time; changing the distance in the MPE equation to:

$$D_{MPE} = \sqrt{\frac{P_{ave} \times G_{abs} \times RRF}{4\pi \times MPE}}$$

Once all the factors are determined, the D_{MPE} can be calculated. The calculated D_{MPE} is in meters; to change the D_{MPE} to feet, multiply the result by 3.28. It is important to note that calculated hazard distance is simply an estimation. The estimated hazard distance is useful in determining a starting point when confirming estimated results with actual measurements.

To demonstrate how to use EMF emitter parameters, the following examples show how to apply the lessons above to an actual EMF radiation emitter.

Example 1

The scenario is an ARC–164 UHF radio on board a KC–135 aircraft (fig. 2–14). The radio antenna is mounted on the lower portion of the aircraft just between the front landing gear and the wing. Determine the risk for an avionics technician testing the emitter.

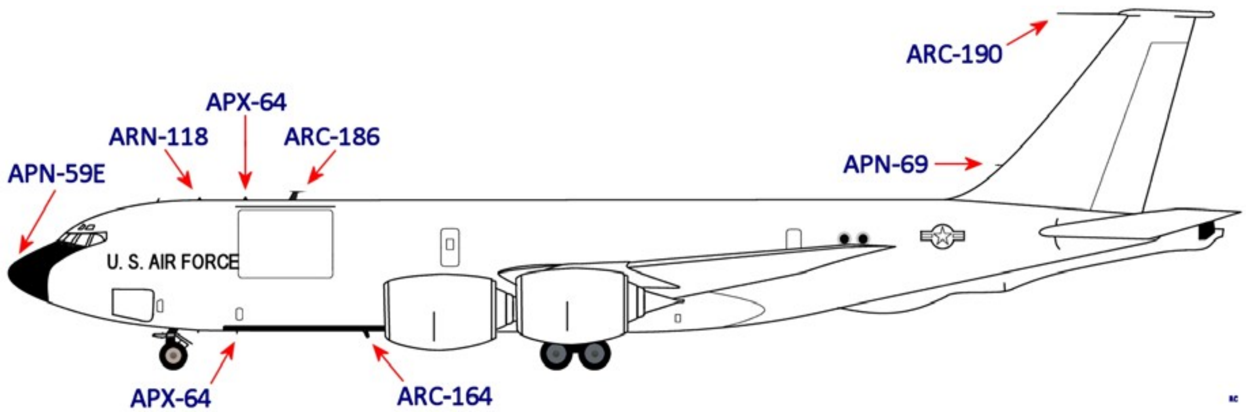

Figure 2–14. KC–135 EMF emitters.

The operating parameters for the ARC–164 radio are:

- Nomenclature: ARC–164.
- Description: UHF radio.
- Frequency: 399.98 MHZ.
- PW: N/A.
- PRF: N/A.
- Peak power: 0.010 kW.
- Antenna gain: 2 dB.
- Antenna type: Dipole.
- Beam width: N/A.
- Sector size: N/A.

Since there is no PW or PRF listed, it can be determined that the emitter operates in a continuous wave mode. Since both the frequency and peak power are low, the system will likely have a relatively short hazard distance. Confirm this initial assessment by calculating the hazard distance for this system.

$$D_{MPE} = \sqrt{\frac{P_{ave} \times G_{abs}}{4\pi \times MPE}}$$

Step 1: Determine the P_{ave}: In the case of a CW system, the P_{ave} is the same as the P_p.

$$P_{ave} = 10 \text{ watts}$$

Step 2: Calculate the absolute gain: Since it is a dipole antenna (not aperture), use the following absolute gain calculation.

$$G_{abs} = 10^{\frac{Gain}{10}}$$

$$G_{abs} = 10^{\frac{2.0}{10}}$$

$$G_{abs} = 10^{0.2}$$

$$G_{abs} = 1.58$$

Step 3: Determine type of environment: An avionics technician testing the emitter would have to be trained on the hazards associated with the antenna. Since this would be an EMF worker, the upper tier environment MPE applies.

Looking back to figure 2–12, find the frequency (399.98) in the far-left column, and then go across the row to find the power density MPE. In this case, the MPE requires a calculation:

$$MPE = \frac{f_M}{30}$$

$$MPE = \frac{399.98}{30}$$

$$MPE = 13.3W / m^2$$

Step 4: Plug in the values and solve the equation.

$$D_{MPE} = \sqrt{\frac{P_{ave} \times G_{abs}}{4\pi \times MPE}}$$

$$D_{MPE} = \sqrt{\frac{10W \times 1.58}{4\pi \times 13.3W / m^2}}$$

$$D_{MPE} = \sqrt{\frac{15.8}{167.54}}$$

$$D_{MPE} = \sqrt{0.0943}$$

$$D_{MPE} = 0.307 \ meters$$

$$0.307 \ meters \times 3.28 feet / meter = 1.01 \ feet$$

The hazard distance for this emitter is 0.307 meters or 1.01 feet. This distance is used to establish controls and make health risk recommendations.

The ARC–164 is a CW system; the next example shows the procedure for a pulsed wave system.

Example 2

The same KC–135 (fig. 2–16) also employs an AN/ARN–118 TACAN. The antenna is located on the top of the aircraft just above the door (fig. 2–13).

The operating parameters for the ARN–118 TACAN include:

- Nomenclature: ARN–118.
- Description: TACAN.
- Frequency: 1150 MHZ.
- PW: 12.5 µsec.
- PRF: 150 pps.
- Peak Power: 0.500 kW.
- Antenna gain: 2 dB.
- Antenna type: Dipole.
- Beam width: N/A.
- Sector size: N/A.

The PW and PRF are listed, indicating the emitter is a pulsed wave system. Calculate the hazard distance for this system.

$$D_{MPE} = \sqrt{\frac{P_{ave} \times G_{abs}}{4 \times \pi \times MPE}}$$

Step 1: Determine the P_{ave} for this PW system using the following formula:

$$DF = PW \times PRF$$

$$DF = 12.5 \times 10^{-6} \sec \times 150 pps$$

$$DF = 1.875 \times 10^{-3}$$

$$P_{ave} = P_p \times DF$$

$$P_{ave} = 500 watts \times 1.875 \times 10^{-3}$$

$$P_{ave} = 0.94 watts$$

Step 2: Determine the G^{abs} for this dipole antenna using the following calculation:

$$G_{abs} = 10^{\frac{Gain}{10}}$$

$$G_{abs} = 10^{\frac{2.0}{10}}$$

$$G_{abs} = 10^{0.2}$$

$$G_{abs} = 1.58$$

Step 3: Determine the upper tier environment MPE from figure 2–12.

Using figure 2–12, find the frequency (1150 MHz) in the far-left column, then go across the row to find the power density MPE. Again, the MPE requires a calculation:

$$MPE = \frac{f_M}{30}$$

$$MPE = \frac{1150}{30}$$

$$MPE = 38.3W/m^2$$

Step 4: Plug in the values and solve the equation.

$$D_{MPE} = \sqrt{\frac{P_{ave} \times G_{abs}}{4\pi \times MPE}}$$

$$D_{MPE} = \sqrt{\frac{0.94 \times 1.58}{4\pi \times 38.3W/m^2}}$$

$$D_{MPE} = \sqrt{\frac{1.48}{481.29}}$$

$$D_{MPE} = \sqrt{0.0031}$$

$$D_{MPE} = 0.055 meters$$

$$0.055\ meters \times 3.28 feet/meter = 0.182\ \ feet$$

The hazard distance for this emitter is a little over two inches. The calculations for both emitters resulted in short hazard distances, but that does not mean there are no emitters without significant hazard distances. The next example is a calculation for the hazard distance of a much more powerful emitter, “Doppler” radar.

Example 3

Figures 2–15 and 2–16 show two common Doppler radars used to predict weather. This example calculates the hazard distance for a stationary position instead of the normal scanning mode in order to show the potential hazard.

Figure 2–15. Outside view of Doppler radar.

Figure 2–16. Inside view of Doppler radar.

The operating parameters for the Doppler radar include:

- Nomenclature: NEXRAD.
- Description: Doppler radar.
- Frequency: 2700 MHZ.
- PW: 4.7 μsec.
- PRF: 452 pps.
- Peak power: 750 kW.
- Antenna gain: 45 dB.
- Antenna type: Aperture.
- Antenna size: 32' (9.75m) diameter.
- Beam width: N/A (held stationary for survey).
- Sector size: N/A (held stationary for survey).

Since the PW and PRF are listed, the emitter is a pulsed wave system. The antenna has been made stationary to enable survey measurements. 'Calculate the hazard distance for this system.

$$D_{MPE} = \sqrt{\frac{P_{ave} \times G_{abs}}{4\pi \times MPE}}$$

Step 1: Determine the P_{ave}. In this case, since it is a PW system, calculate the average power using the following formula:

$$DF = PW \times PRF$$

$$DF = 4.7\times10^{-6}\sec\times 452\,pps$$

$$DF = 2.12\times10^{-3}$$

$$P_{ave} = P_p \times DF$$

$$P_{ave} = 750\times10^{3}\,watts\times 2.12\times10^{-3}$$

$$P_{ave} = 1593.3\,watts$$

Step 2: Calculate the G_{abs}. Since it is an aperture antenna, use the following G_{abs} calculation. Break this step into three parts.

$$G_{abs} = \frac{4\pi A}{\lambda^2}$$

First, calculate the wavelength of the emitter (λ).

$$\lambda = \frac{3\times10^{8}\,m/\sec}{f}$$

Where:

$3x10^8$ m/sec = (speed of light constant)

f = emitter frequency in Hz.

$$\lambda = \frac{3\times10^{8}\,m/\sec}{2700\times10^{6}\,Hz}$$

$$\lambda = 0.11\,meters$$

Then, solve for the area of the antenna in meters (A).

$$A = \pi\,\mathrm{r}^2$$

$$A = \pi\left(\frac{9.75m}{2}\right)^2$$

$$A = 74.76m^2$$

Finally, solve for the G_{abs}.

$$G_{abs} = \frac{4\pi A}{\lambda^2}$$

$$G_{abs} = \frac{4\pi(74.76m^2)}{(0.11m)^2}$$

$$G_{abs} = \frac{939.4}{0.0121}$$

$$G_{abs} = 77{,}637$$

Step 3: Determine the upper tier environment MPE from figure 2–12. Find the frequency (2,700 MHz) in the far-left column, and then go across the row to find the power density MPE. Again, the MPE requires a calculation:

$$MPE = \frac{f_M}{30}$$

$$MPE = \frac{2700MHz}{30}$$

$$MPE = 90W/m^2$$

Step 4: Plug in the values and solve the equation.

$$D_{MPE} = \sqrt{\frac{P_{ave} \times G_{abs}}{4\pi \times MPE}}$$

$$D_{MPE} = \sqrt{\frac{1593.3W \times 77{,}637}{4\pi \times 90W/m^2}}$$

$$D_{MPE} = \sqrt{\frac{123{,}699{,}032}{1131}}$$

$$D_{MPE} = \sqrt{109{,}374m^2}$$

$$D_{MPE} = 330.7meters$$

The hazard distance for this emitter is 331 meters or 1,085 feet.

The calculated hazard distances above were all for emitters with stationary antennas. What about an emitter with an antenna that rotates?

Example 4

Use the following values if there are both vertical and horizontal beam widths with different values:

Vertical beam width value if the antenna motion is up and down.

Horizontal beam width value if the antenna sweeps back and forth or rotates horizontally.

Given the following operating parameters for the scanning system shown in figure 2–15, the hazard distance calculation is shown below:

- Description: Radar.
- Frequency: 125 MHZ.
- PW: 1.4 µsec.
- PRF: 260 pps.
- Peak power: 5,800 kW.
- Antenna gain: 45 dB.
- Antenna type: Aperture.
- Antenna size: 12’ X 8’.
- Beam width: 1.3°.
- Sector size: 180°.

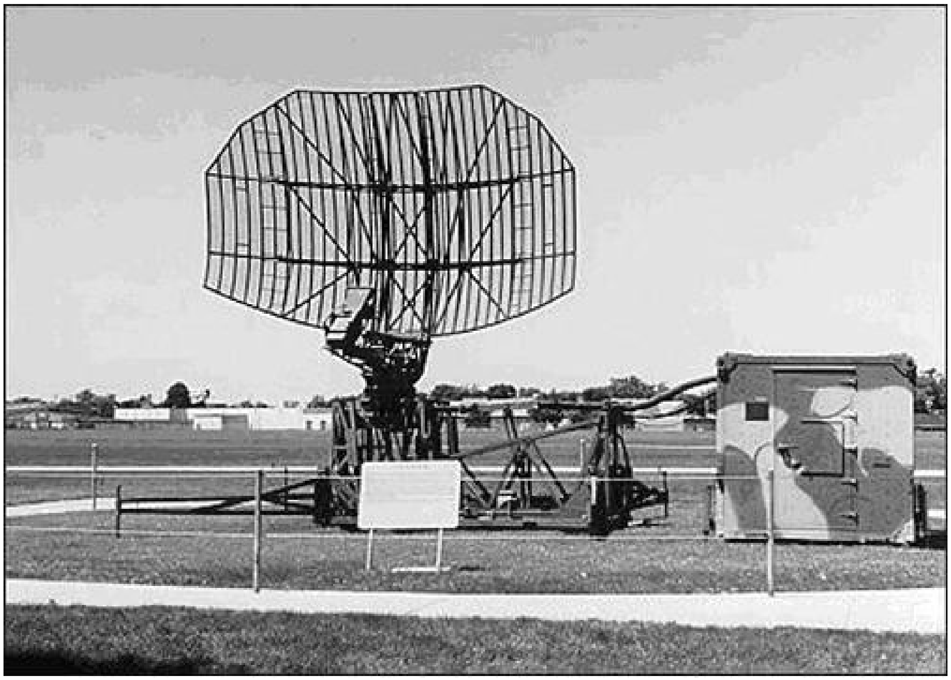

Figure 2–17. Scanning system.

The PW and PRF are listed, so the emitter is a pulsed wave system. Since the antenna is rotating also, use the formula with the RRF.

$$D_{MPE} = \sqrt{\frac{P_{ave} \times G_{abs} \times RRF}{4\pi \times MPE}}$$

Step 1: Determine the P_{ave} for the PW system using the following calculation:

$$DF = PW \times PRF$$

$$DF = 1.4 \times 10^{-6} \sec \times 260\, pps$$

$$DF = 3.64 \times 10^{-4}$$

$$P_{ave} = P_p \times DF$$

$$P_{ave} = 5800 \times 10^3\, watts \times 3.64 \times 10^{-4}$$

$$P_{ave} = 2111.2 watts$$

Step 2: Determine the G_{abs} for this aperture antenna using the following calculation:

$$G_{abs} = \frac{4\pi A}{\lambda^2}$$

First, calculate the wavelength of the emitter (λ).

$$\lambda = \frac{3 \times 10^8 \, m/\sec}{f}$$

$$\lambda = \frac{3 \times 10^8 \, m/\sec}{125 \times 10^6}$$

$$\lambda = 2.4 meters$$

Then, solve for the area of the antenna in meters (A).

$$A = L \times W$$

$$A = 3.66m \times 2.44m$$

$$A = 8.92m^2$$

Finally, solve for the G_{abs}.

$$G_{abs} = \frac{4\pi A}{\lambda^2}$$

$$G_{abs} = \frac{4\pi 8.92m^2}{(2.4meters)^2}$$

$$G_{abs} = \frac{112.09}{5.76}$$

$$G_{abs} = 19.46$$

Step 3: Determine the Upper Tier Environment MPE. Using figure 2–14, find the frequency (125 MHz) in the far-left column, and then go across the row to find the power density MPE.

$$MPE = 10 \ \text{W/m}^2$$

Step 4: Find the RRF.

$$RRF = \frac{BeamWidth}{SectorSize}$$

$$RRF = \frac{1.3}{180}$$

$$RRF = 0.0072$$

Step 5: Plug in the values and solve the equation.

$$D_{MEPE} = \sqrt{\frac{P_{ave} \times G_{abs} \times RRF}{4\pi \times MPE}}$$

$$D_{MPE} = \sqrt{\frac{2111.2W \times 19.46 \times 0.0072}{4\pi \times 10W / m^2}}$$

$$D_{MPE} = \sqrt{\frac{295.8}{125.66}}$$

$$D_{MPE} = \sqrt{2.35m^2}$$

$$D_{MPE} = 1.53 meters$$

The hazard distance for this emitter is 1.53 meters or 5 feet while it is rotating. If the emitter's rotation is stopped to take measurements, the hazard distance will be significantly greater (18 meters or almost 60 feet). This distance is obtained by removing the RRF in the equation above.

Up to this point in survey process, no measurements have been taken. However, knowing the hazard distance provides a good starting point for sampling. It may not always be necessary to take measurements. In many cases, the emitters have been in the same location for many years, and as long as the parameters do not change, revalidating measurements may not be necessary. Instead, perform a site inspection to verify parameters and controls, and then use the results to justify measurements.

611. Performing electromagnetic frequency radiation measurement surveys

According to AFI 48–109, initial measurement surveys must be accomplished on emitters capable of producing levels at or above the MPEs unless excluded under the low-power device exclusion rules or existing measurement survey data can be applied under local conditions.

It is important to understand the capabilities and limitations of field measurement instrumentation. Knowing the equipment will avoid unnecessary exposure to survey personnel and prevent damage to instruments. Particular care must be taken to ensure that probe peak power limits are not exceeded since this can damage equipment.

Electromagnetic frequency radiation instruments and use

The standard instrument used for EMF radiation measurements is the Narda Broadband Isotropic Radiation Monitor. Since the probes are isotropic, they do not have to be held in one precise location; it can accurately measure when held at a variety of angles. Although there are many different model numbers, figures 2–18 and 2–19 illustrate models most commonly used by BE. Each meter can use a number of probes (fig. 2–20) that provide response to different frequency and power density ranges. The electric field probe is used for routine measurements. It is important to not use Narda's magnetic field probe for routine measurements, as the results will be inaccurate and could lead to an inaccurate health risk assessment.

A typical radar beam has a pulse width on the order of a few millionths of a second, but the radiation monitor cannot measure the P_p of a beam, unless the pulse width is greater than 0.25 second. The slow response of both the meter and the probes limits the system to measurements of average power density for pulsed transmissions. This slow response also makes it very difficult to measure scanning radar; so, this type of beam is usually measured with the antenna fixed in-place.

Figure 2–18. Narda Broadband Isotropic Radiation Monitor model 8712.

Figure 2–19. Narda Broadband Isotropic Radiation Monitor model 8611.

Figure 2–20. Narda Broadband Isotropic Radiation Monitor EMF probe.

Correction factors

Narda probes are calibrated at many discreet frequencies. Probe correction factors are printed on the probe handle for different frequency points. After obtaining meter readings, results must be multiplied the by the correction factors found on the probe handle in order to identify the actual power density. The correction factors depend on the frequency of the radiation being monitored and represent the fraction of the true power density. If the emitter frequency is between two values, a correction value can be calculated by linear interpolation of the two values. As an example, suppose an emitter operates at 4,000 MHz and the probe correction factors for 3,000 MHz and 5,000 MHz are 0.9 and 0.95, respectively. Then, the appropriate correction factor for 4,000 MHz is 0.925.

Probe burnout

An important point to remember when using a meter is that probes are sensitive to overloading. When monitoring potentially high radiation fields, probes can burnout easily. The thin-film thermocouples are very sensitive elements that are susceptible to overload or burnout when exposed to very high power density fields. It is important to note that the probes are susceptible to burnout even if the meter is off or if the probe is disconnected.

The maximum peak power density that a probe can withstand before burnout occurs is normally printed on the handle of the Narda probe. The burnout characteristic is typically three times full scale in terms of average values. Newer designs of thermocouple instruments have burnout ratings of 15-20 times full scale.

Probe burnout is not particularly a problem in taking measurements of CW emissions because the probe burnout threshold is significantly higher than the maximum possible meter reading. As long as the surveyor is monitoring the meter and does not allow it to exceed a full-scale deflection, one does not risk probe burnout. Of course, one must observe the scale on the meter that matches the probe in use.

The burnout problem becomes complicated in the case of pulsed EMF signals because the probe elements can burn out instantly. Levels high enough to cause probe burnout are possible when taking measurements of pulsed signals with very short duty factors, even at meter deflections less than the full-scale deflection value of the meter or even the MPE. In this case, the average transmitted power may be very low while the peak power is very high. If the peak power absorbed by the probe exceeds the peak overload value, the probe will fail even though the average power indicated by the meter is a value less than full scale.

In order to avoid probe burnout, probes have a manufacturer-specified power density range for safe operation. The appropriate power density range is codified in the model number. Probe model numbers ending with a "1," such as 8631, are for low power densities—up to 20 mW/cm^2. Those ending with "2," such as 8652, are higher-range—up to 200 mW/cm^2. Those ending with "3" are mid-range—up to 100 mW/cm^2. When there are multiple scales on a meter, such as shown in figure 2–19, the probe used will determine which scale to use. The probe model numbers also indicate the frequency range that the probe covers; so be sure to get the right probe for the radiation frequency to be monitored.

Remember that the meter measures average power, but probe burnout depends on the peak power. The formula that follows should be used to check for this possibility before entering radiation areas with pulsed emitters:

$$PD_{max} = \frac{\text{duty factor x probe burnout rating}}{\text{probe correction factor}}$$

The PD_{max} represents the maximum meter reading (even though the meter may not go that high) that can be displayed before burnout occurs. For example, a radar transmitter operating at 11,000 MHz (11 GHz) has a pulse width of two microseconds and a pulse repetition frequency of 500 pulses per second, which gives a duty factor of 0.001. The probe to be used has a peak power rating listed as 60 $watts/cm^2$, which must be expressed in the calculation as 60,000 mW/cm^2. The meter scale has a maximum of 20mW/cm^2. The correction factor at 4000 MHz for this particular probe is 0.88. The PD_{max} is:

$$PD_{max} = \frac{0.001 \text{ x } 60{,}000}{0.88}$$

$$PD_{max} = 68.2 mW / cm^2$$

Assuming probe 8631 (has a number ending with a "1,") is used, which is designed for low-power densities up to 20 mW/cm^2, the probe should not burn out if efforts are made to avoid full-scale readings. A PD_{max} of less than 20 mW/cm^2 would mean this probe could burn out easily before a full-scale meter reading is reached. Thus, the meter would have to be watched very closely while monitoring.

So far, the potential health risks have been identified by conducting a site assessment and hazard distance has been assessed by conducting calculations. With these tasks accomplished, the next step is to prepare for the measurement survey.

Radiofrequency radiation measurement surveys

A successful survey is a safe survey that produces the necessary data and results in the understanding and satisfaction of all the key stakeholders. In order to take appropriate measurements, it is critical for both survey and shop personnel to have full control over the emitter and the survey area, especially since the measurement itself may require deviation from normal operations. A surprising number of accidental exposures have occurred while surveying EMF emitters.

Before measuring begins, survey personnel should call the shop where the emitter is located to ensure the equipment and operators are available. The shop operators should notify the unit radiation safety officer if applicable. Also check survey equipment and determine whether any other items, such as handheld radios, may be needed. Upon arrival at the site, brief everyone regarding how, and why the survey will be executed. This is the time to establish procedures that completely control (to the extent possible) EMF output to ensure no accidental overexposures occur. It's important to make absolutely sure there is adequate communication between survey personnel and emitter operators.

Since the power densities from multiple emitters are additive at any point where their fields overlap, it is essential that all emitters in the vicinity, other than the one being measured, be shut down while initial measurements are made. Contributions from other emitters at the point of interest should be independently measured then added to make a set of contours identifying the MPE distance. It may not always be possible to isolate each contributing antenna. In this case, measurements should be taken using a "shaped" probe which measures in percentage of standard. Assistance from USAFSAM may be required in this situation.

Before the transmitter is activated, be sure there is an ample clear area in front of the antenna to avoid irradiating buildings, vehicles, and so forth. This is particularly important in the case of aircraft radar in which the beam is normally accessible and often near ground level (fig. 2–21). Maintenance on aircraft radar is one of the most hazardous EMF operations. Be sure all necessary precautions are taken, such as using dummy loads to contain and absorb the beam, utilizing signs, flashing lights, and adequate safety procedures, and roping off the area. Survey personnel should avoid exposing themselves or others to the main beam or any other potentially hazardous field. If needed, place instrument probes on non-conducting extensions where possible. Personnel exposure must not exceed the applicable MPE.

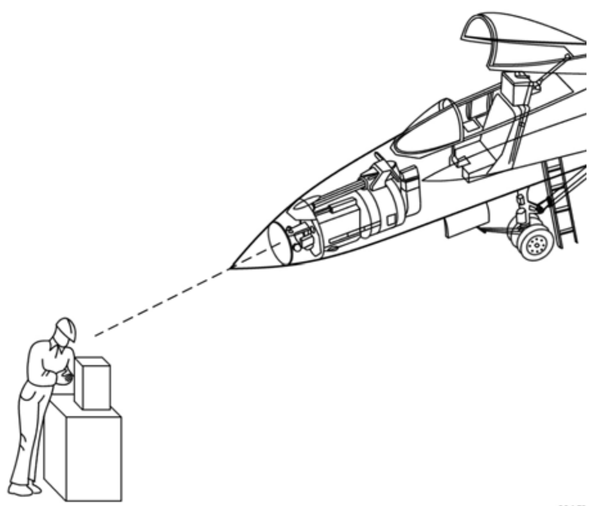

Figure 2–21. Aircraft EMF emitter survey.

Worst-case operating parameters under fixed-beam conditions should be used to define the location of hazard distances whenever possible. This is particularly important when locating new ground systems. Measurements should be conducted to determine two hazard distances, one for the upper tier environment and one for lower tier environments. General guidelines for survey procedures are outlined below. Exact procedures to follow during set-up and performance of a survey will vary somewhat for different emitter types. Detailed notes for survey procedures are given in USAFSAM *Base-Level Guide for Electromagnetic Frequency Radiation* (AFRL–SA–WP–SR–2013–0003). Ground-mounted EMF emitter procedures are in Appendix C, airborne EMF emitters in Appendix D, and non-antennae field generating devices in Appendix E. An EMF Survey Checklist is provided in Appendix F.

If mission requirements or safety interlock devices preclude making worst-case measurements, normal operating parameters should be used to identify hazardous areas. If fixed beam measurements are not possible when an actual measurement is required, it may be possible to locate an averaging module to assess power density fields in accessible areas (USAFSAM may be able to help locate instrumentation).

Scanning antennas should be stopped and the beam positioned parallel to the ground, or slightly elevated, to prevent reflections and make measurement easier. Transmitters that operate in multiple modes should be set for worst-case conditions (i.e., highest average power, narrowest beam, and most restrictive (MPE-wise) frequency). If the operators have the proper equipment, actual power input to the antenna during the survey should be determined.

Ensure that the probe is calibrated and covers the frequency and power density ranges expected, and then connect it to the meter. Turn the meter on 10 minutes before taking any measurements to allow it to stabilize. Afterward, and periodically throughout the survey, the meter may need to be set to zero by adjusting the zero control on the meter face. Do this in an area that is a similar temperature to the survey site and shielded from the EMF. Determine which meter scale to observe according to the probe in use, and always begin at the highest power density setting for that probe. The setting can be adjusted down as needed during the survey. Although this may seem obvious, make sure that the EMF system is transmitting before beginning to walk around with the meter. Also, always begin the survey at a distance greater than the estimated MPE distance, with the meter on its maximum range setting, while remaining mindful of probe burnout distance.

Reasonably accurate readings can be obtained in the near field using the standard electric field probe for frequencies above 30 MHz. USAFSAM recommends measuring both the electric and magnetic fields for frequencies below 300 MHz. Identify nearby objects that may cause unwanted reflections. Be careful not to overexpose survey personnel, especially if anyone happens to be near the dangerous area between the feedhorn and dish of an aperture antenna.

The probe should be extended in front of the surveyor's body at full arm's length to avoid reflections from the body. Try to avoid, or at least be aware of, reflections from surrounding objects, and keep the probe parallel to the ground. After locating the main beam, determine its size and shape and then advance slowly until the true MPE distance is accurately located. Next, check the area surrounding the antenna for hazardous levels other than the main beam (side lobes, back lobes). In addition to the main beam hazard, look for localized hot spots produced by reflections from metal surfaces and fences, coupling of the beam, and side lobes. These can occur in areas having general power densities less than the MPE. Finally, brief the supervisor on findings and what control measures may be recommended once all the data has been fully analyzed.

Based on potential for exposure and changes to parameters, periodic reassessment or measurement of EMF areas may be needed to determine whether equipment, configurations, or procedures have changed. A few areas should receive quarterly visits. These include aircraft radar and ECM systems in flightline and shop areas where dummy loads are used, radar systems that can direct a stationary EMF beam into areas that people can occupy, and other potentially hazardous emitters that can have rapidly changing operating parameters (such as laboratory setups). Additionally, make periodic measurements in shop areas with equipment that radiates EMF into free space.

For systems where the beam is clearly inaccessible to personnel during normal operations, initial measurements should be performed to confirm beam inaccessibility, and to probe occupied work areas for leakage from transmitter cabinets, waveguides, cables, and so forth. All operating procedures and work practices must be thoroughly evaluated to ensure there are no conditions under which the beam is accessible to personnel.

Analyzing and documenting risk

When a new EMF emitter has been added to an installation, it is necessary to enter the emitter into the shop inventory and complete the corresponding steps for an EMF survey, both in DOEHRS. DOEHRS includes non-ionizing radiation and EMF and enables authorized users the ability to document all types of radiation surveys. These surveys are then compared to guidelines for potential risks that are physical in nature. Detailed procedures are available in Appendix A of USAFSAM *Base-Level Guide for Electromagnetic Frequency Radiation*.

It is important to know acronyms used in DOEHRS, in order to obtain information during the survey required to complete the DOEHRS entries. The following acronym codes can be used in DOEHRS to identify items where field space is limited.

Antenna code

The codes in the table below identify the type of antenna observed.

BL	Blade (or fin)		OD	Other Directional
CR	Circular Reflector		OO	Other Omnidirectional
DC	Discone		PA	Phased Array
DI	Discage		RH	Rhombic (or V)
DL	Dummy Load		RR	Rectangular Reflector
DP	Dipole or Dipole Array		SL	Slots/Slot Array
HC	Horn (plane, conical or biconical)		SP	Spiral
HE	Helix (helical)		ST	Stub
HL	Horizontal Log Periodic		VL	Vertical Log Periodic
LE	Lens		WA	Waveguide Array (slot/hole)
LO	Loop		WH	Whip (or long wire)
LW	Long Wire		YA	Yagi or Yagi Array
MO	Monopole or Colinear Array			

Scanning code

Use one or more of the following codes to describe the motion of the antenna beam.

F	Fixed
R	Rotating, 360 degrees
T	Tracker*
S	Sector Scan (Mechanical)*
E	Sector Scan (Electronic)*
***NOTE:** If S or E is entered, also enter the width in degrees of the scanned sector.	

Estimated Hazard Distance

The estimated hazard distance in feet theoretically derived. Indicate one of the following codes in parenthesis in addition to the numerical distance.

F	Fixed
T	Rotating, 360 degrees
N	Tracker*
O	Sector Scan (Mechanical)*

Hazard Code—Once the parameters for an emitter have been inventoried and recorded, the next step is to determine the hazard code. Sometimes this task is difficult to complete for BEE technicians who have very little EMF experience. The major factor determining the hazard code is based on accessibility of personnel. Hazardous areas that are well above ground level or in some other way not normally accessible are labeled “IH” or “CH” and are regarded as a small concern. Sometimes only a BEE Tech, looking directly at a particular emitter, can make this determination. The following codes in the table can help to describe the hazard category into which the emitter falls.

NH	No levels generated in excess of the MPE.
IH	Hazardous levels possible but in normally inaccessible areas.
CH	Hazardous levels possible but only in areas that require climbing.
GH	Ground-level hazardous exposures possible.
DL	Transmitter dummy loaded.
SH	Hazardous levels possible, but transmission time is too short for overexposure.
OD	Other device (non-antenna); no levels generated in excess of the MPE.
OE	(non-antenna); levels generated in excess of the MPE.

Hazard Control Code—Once survey work is complete, the next step is to determine necessary control measures and/or evaluate existing control measures. For emitters that are nonhazardous or have hazard zones that are inaccessible, there is no requirement for any control measures. For emitters that create accessible hazard zones, the following codes in the table below can help to describe the recommended controls for this system.

AS	Audible signal		LF	Locked fence
BA	Rope or chain barrier		NR	No control required
BL	Blanking		OM	Other (please describe)
CO	Constant observation when transmitting		SC	Special coordination when transmitting
FE	Fence		SO	Standard operating procedure in effect
FL	Flashing light		WS	Warning signs
IN	Interlock			

Documentation—After the site visit, analyze the data and formulate final conclusions and recommendations. Prepare a report and send a copy to the supervisor owning the EMF source. Where a new EMF emitter has been added to an installation, send the emitter parameters into USAFSAM through the Environment, Safety, and Occupational Health (ESOH) Service Center at **esoh.service.center@wpafb.af.mil** for inclusion into the Radiofrequency Emitter Inventory. AF 2759 Forms still can be used to keep handwritten field notes of case file EMF data, but should not be considered the primary record. The DOEHRS data is the primary record. The AF 2759 also can be scanned and kept as an attachment in DOEHRS. Documentation shall include:

1. A brief hazard assessment narrative summarizing the potential hazards involved with the use and operation of the specific emitter.
2. The exact locations where the MPEs can be exceeded for both upper and lower tier areas should be included and demonstrated in a diagram or photograph.
3. Facilities personnel responsible for the use and operation of emitters capable of producing levels at or above the MPE should also have an entry in DOEHRS.

USAFSAM *Base-Level Guide for Electromagnetic Frequency Radiation* (AFRL–SA–WP–SR–2013–0003) should be referenced before, during, and while documenting any EMF survey, as detailed steps and explanation of terms and codes are included.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

608. Performing electromagnetic frequency radiation risk assessments

1. What should you do if the frequency of an emitter is classified?

2. What types of emitters should you make your highest priority for surveys?

609. Determining electromagnetic frequency radiation permissible exposure limits

1. Using figures 2–11 and 2–12, find the power density MPE for an emitter operating at 2700 MHz in a controlled environment.

2. Using figures 2–11 and 2–12, find the power density MPE for an emitter operating at 300 MHz in an uncontrolled environment.

3. Using figures 2–11 and 2–12, find the power density MPE for an emitter operating at 30 MHz in a controlled environment.

610. Calculating hazard distances

1. What is the absolute gain for a dipole antenna with a gain of 12 dB?

2. What is the duty factor for the emitter with the following parameters?
   - Nomenclature: 164.
   - Description: Radar.
   - Frequency: 399.98 MHz.
   - Pulse width: 2 µsec.
   - Pulse repetition frequency: 450 pp.
   - Peak Power: 10 kW.
   - Antenna gain: 2 dB.
   - Antenna type: Dipole.

3. What is the average power for the emitter with the following parameters?
   - Nomenclature: 19.
   - Description: Radar.
   - Frequency: 400 MHZ.

- Pulse width: 3 µsec.
- Sector size: N/A.
- Pulse repetition frequency: 600 pps.
- Peak Power: 50 kW.
- Antenna gain: 15 dB.
- Antenna type: Dipole.
- Beam width: N/A.

4. What is the rotational reduction factor for the following emitter?

- Frequency: 125 MHZ.
- Gain: 45 dB.
- Peak Power: 5800 kW.
- Sector Size: 90°.
- Pulse width: 1.4 µsec.
- PRF: 260 pps.
- Beam width: 1.3°.

5. What is the estimated hazard distance for the following emitter (in feet)?

- Frequency: 399.98 MHZ.
- PW: N/A.
- PRF: N/A.
- Peak Power: 0.010 kW.
- Controlled area.
- Antenna gain: 2 dB.
- Antenna type: Dipole.
- Beam width: N/A.
- Sector size: N/A.

611. Performing electromagnetic frequency radiation measurement surveys

1. After obtaining meter readings, how do you determine the actual power density of the emitter?

2. What type of emitter has a higher risk of probe burnout?

3. Calculate the PD_{max} for an emitter and probe with the following parameters:

- Duty Factor: 2 µsec.
- Burnout Rating: 600,000 mW/cm^2.
- Probe Correction Factor: 1.2.

4. What type of operating parameters should you use to define the location of hazard distances?

5. How should you hold the probe when taking EMF measurements?

2–3. Radiofrequency Radiation Controls

The ultimate goal of every occupational or environmental health and safety program is to control hazards that can't be otherwise eliminated in the workplace.

612. Electromagnetic frequency radiation controls

This lesson will address engineering controls, administrative controls, and some additional considerations with regards to electromagnetic frequency radiation.

Engineering controls

Most of the engineering controls applied to EMF operate on the principle of preventing transmission. Azimuth blanking is a common engineering control for search radars. "Azimuth" is a navigational term that essentially refers to a point of interest within a spherical plan. Azimuth blanking prevents EMF systems from transmitting when the emitter is pointed in a particular direction/point (azimuth) within its rotation, or physically restricts the radar from pointing in a certain direction/azimuth. Interlocks are used to automatically switch off the emissions when a door, hatch, or other entry point is breached. In some high hazard areas, kill switches or panic buttons may be installed inside rooms where antennas are located to stop emitters in an emergency. Dummy loads used instead of antennas to preclude free space irradiation inside the shop area are another common engineering control. When properly connected on a bench test system, dummy loads are most effective. However, they occasionally experience cracks that may result in EMF leakage.

Administrative controls

Administrative controls include training, restricting access, and using visual warning devices. Most people avoid hazards, so one of the measures to limit exposure is to make personnel aware of the hazards. Make sure personnel are aware by posting signs (fig. 2–22) to indicate EMF upper tier environments, lower tier environments, and high-level areas where personnel may have access to 10 times the upper tier environment MPEs. Using cones and/or roped-off areas with warning signs also helps.

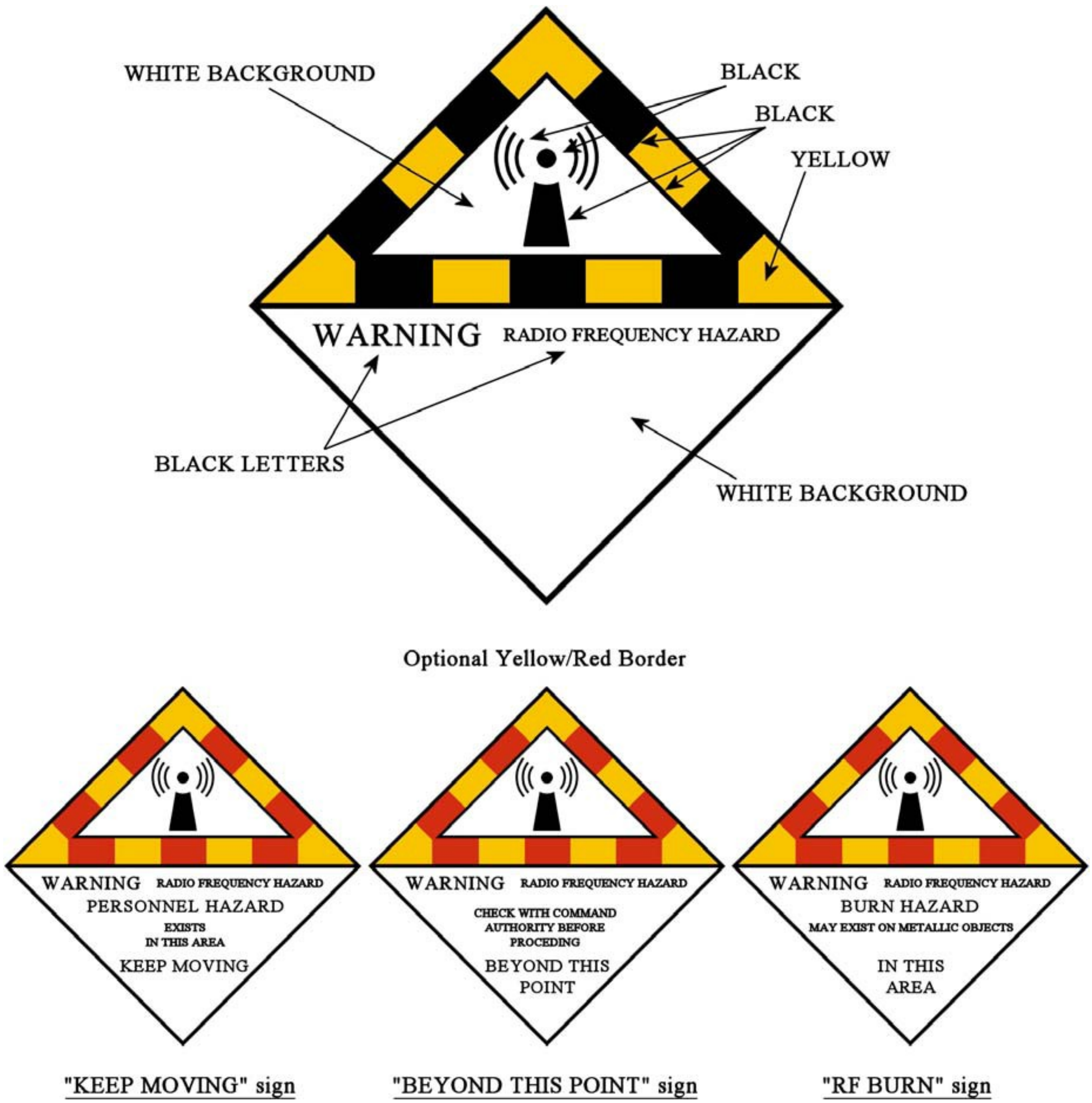

Figure 2–22. EMF hazard warning signs.

Depending on potential risk of exposure, other warning devices such as flashing lights, audible signals, or barriers are required to ensure personnel safety. Metal chain link or wooden fences may be utilized to control access to hazardous areas. Nonconductive wooden fences are commonly used around high-frequency emitter sites due to the potential for metal objects to passively reradiate EMF.

Posting a qualified operator or technician to observe the illuminated area during transmissions is an administrative control that may be used where permanent posting or roping off an area is not feasible or functional. Prior coordination prevents workers from inadvertently accessing areas that could exceed the MPEs. Busy installation should be coordinated so personnel working in both directions (emitter controllers or operators and maintenance personnel) are aware of each other’s actions before proceeding.

Additional considerations

Personnel are protected from electric shock and burns by utilizing electrical safety matting, electrical safety shoes, or other isolation techniques. These items are specifically required for upper tier areas where frequencies are below 30 MHz as electric shock and burns are the primary hazards.

Even though guests in hazard areas are not recommended, it is prudent for unit commanders and supervisors to inform visitors when they will be entering an upper tier environment and ensure they know about the potential hazards/risks, observe signs, and remain out of restricted areas.

Unlike most other health hazards, personal protective equipment (aside from electrical safety shoes) is not advocated or authorized for EMF exposure.

The hazard controls can be somewhat difficult to determine and largely depend on common sense. For instance, in a maintenance shop, it may only be necessary to place warning signs at entrances and transmitter work stations when dummy loads are used. If dummy loads cannot be used for some tests, locking the doors during the operation is a simple answer. Placing traffic cones or ropes with warning signs around emitters used outdoors is another plan, as long as the boundaries encompass the hazard zone. Generally, beams from antennas on towers are inaccessible to people, but there could be high levels on the ground due to secondary EMF field lobes. These are controlled easily by fencing off the area and strictly controlling access. Many antennas are found on rooftops, but access to these is simply prevented by using signs, chains across stairways to roof entrances, and locked doors. The key is really the magnitude of the hazard distance and the accessibility to the EMF beam.

613. Investigating potential overexposures to electromagnetic frequency radiation

When all the controls discussed in the previous lesson fail, an exposure can occur. A potentially exposed individual is required to immediately report the incident to his or her supervisor and seek medical attention within the first 72 hours following exposure. The workplace supervisor must notify BE upon initial report of the incident. Upon receiving such notification, BE is responsible for initiating an EMF investigation to determine if the MPE was exceeded. The procedures for conducting the investigation can be summarized as:

1. Make initial notifications of the incident.
2. Conduct a preliminary investigation.
3. Reconstruct the incident and collect field measurements when necessary.
4. Estimate exposure.
5. Prepare a final report.

Notifications

After notifications are made by the potentially exposed individual and supervisor, BE must in-turn complete the initial notifications required by AFI 48-109. At the onset of the incident, it is a good idea to remind the workplace supervisor to have the potentially exposed individual report for a medical evaluation and collect written statements from all persons involved or who witnessed the incident. These statements will aid the investigation.

Preliminary investigation

During the initial reporting phase of an incident, an experienced BEE or BEE technician can predict or estimate whether or not the potentially exposed individual could have exceeded the MPE, and by how much. This can be done locally or through contact with the consultants at USAFSAM. This is where the emitter information collected previously for the EMF inventory is critical. If the initial estimate indicates exposures may have exceeded five times the adjusted MPE, documentation of EMF measurements, medical examination, and a description of the circumstances and preventive measures must be forwarded to USAFSAM or delegated authority so the report can be maintained in a file repository. Even with less than five times the MPE, it’s a good practice to complete and document the investigation.

Reconstructing the incident/collecting measurements

Ultimately, BE will conduct a preliminary investigation of the alleged incident and perform an incident reconstruction to include field measurements when necessary. Chapter 4 of AFI 48-109 and Chapter 9 of USAFSAM *Base-Level Guide for Electromagnetic Frequency Radiation* (AFRL–SA–WP–SR–2013–0003) give specific instructions. It begins with the emitter information on the EMF inventory, and includes interviews with personnel and witnesses involved. Take photos, measure distances, estimate times at positions, take EMF measurements, and, above all, ensure safety during incident reconstruction.

Any measurements taken to supplement the investigation should be made using the system parameters used when the incident occurred. However, if the antenna was rotating or the beam was scanning, they must be put in a stationary position for the investigation measurements. A rotational duty factor can be calculated and multiplied by the stationary power density measurement later in the investigation to obtain the individual's actual exposure level from the moving beam. The purpose of reconstructing the incident is to estimate the power density at the exposed person's position(s) during the incident. This, combined with the length of exposure, will give a time-weighted average exposure.

Estimating exposure

The power density at the location must be determined where the person was standing or sitting at the time of the alleged exposure. Document if they were in the near or far field. Remember, the E and H fields behave differently in each of these fields and the power density will be different. To determine if the individual was in the near or far field, calculate these boundaries. If the result of the calculation is less than where the individual was standing, use the far-field power density formula.

Calculating the near and far field boundaries

In order to perform the boundary calculation, the emitter wavelength, type of antenna, and the frequency must be known to determine the appropriate near-field power density calculation. There are three possible calculations to choose from:

Formula for near field boundary for a circular antenna:

$$R_{nf} = \frac{D^2}{(4)(\lambda)}$$

Where:

R_{nf} = farthest boundary of the near field
D = diameter of the antenna
λ = wavelength of the emitter

NOTE: Diameter of the antenna and wavelength of the emitter must be the same units.

Formula for all other aperture antenna:

$$R_{nf} = \frac{L^2}{(4)(\lambda)}$$

Where:

R_{nf} = farthest boundary of the near field
L = the longest dimension (at any given point) of the antenna
λ = wavelength of the emitter

Notice the only difference in the two near field boundary formulas is the variable for the diameter of the antenna and the longest dimensions. Remember, the size and shape of the antenna in part determines the wavelength. Wavelength is related to the distance of the near- and far-field antenna regions.

Formula for dipole, monopole or similar antenna:

The calculation for the near-field boundary for a dipole, monopole or similar antenna is not really a calculation, but rather a rule. When dealing with a dipole, monopole or similar antenna operating at a frequency less than 300 MHz, the near field is less than the wavelength.

Use the hazard distance calculation identified in lesson 610 to solve for the wavelength. The near field will be less than the wavelength. Once the field is determined, the power density to which that person was exposed can be determined.

Calculating power density

If reenactment and calculations determine the individual was standing in the near field when they were exposed, the near-field power density formula will determine the power density to which they were exposed:

$$S_{nf} = 4\frac{(P_{avg})}{A}$$

Where:

S_{nf} = maximum possible power density in the near field (W/m^2)
P_{ave} = average power output of the emitter (W)
A = area of the antenna (m^2)

If reenactment and calculations determine the individual was standing beyond the near field when they were exposed, the far-field power density formula will determine the power density to which they were exposed:

$$S_{ff} = \frac{(P_{ave})(G_{abs})}{(4\pi)(R^2)}$$

Where:

S_{ff} = maximum possible power density in the far field (W/m^2)
P_{ave} = average power output of the emitter (W)
G_{abs} = absolute gain (unitless)
R = distance to the location of worker during exposure (m)

For example, 45 feet from a circular antenna. The 15,000 MHz radar system has an average power of 72 watts and an absolute antenna gain of 10,000. Using parameters of 60 cm for the antenna dish diameter, 2 cm for the EMF wavelength, and the boundary equations for systems operating above 300 MHz, calculate the near field boundary to see which power density equation is more appropriate to give a reasonable estimate of the power density at 45 feet.

$$R_{nf} = \frac{D^2}{(4)(\lambda)}$$

$$R_{nf} = \frac{60^2}{(4)(2)} = 450 \text{ cm (15 feet)}$$

Thus, the exposure distance of 45 feet is well beyond the near-field boundary, indicating the individual was in the far field during the alleged exposure. Then estimate the power density at the point of exposure using the far field power density formula:

$$S_{ff} = \frac{(P_{ave})(G_{abs})}{(4\pi)(R^2)}$$

$$S_{ff} = \frac{(72)(10{,}000)}{(4\pi)\,(45/3.28)^2} = 304.4\ \text{W/m}^2$$

NOTE: The distance (feet) must be converted to meters by dividing by 3.28.

If the system was scanning radar, we would use the following formula:

$$S_{ff} = \frac{(P_{avg})(G_{abs})(\text{beam width})}{(4\pi)\,(R^2)(\text{sector size})}$$

Note: the beam width and sector size are to be in degrees.

AFI 48-109, Table A.2.1. lists the MPE for 15,000 MHz as 100 W/m^2. Comparing the calculated power density to this MPE would appear to indicate an overexposure. Remember, however, that exposure is also a function of time. Although most EMF exposures are averaged over a 6-minute time, careful inspection of AFI 48-109, Table A2.1 shows that the exposure period must be calculated for this frequency.

Time weighted average

The time weighted average (TWA) for a single frequency exposure is straightforward and not much different than the TWA for chemical inhalation exposures. The biggest difference is the time in which EMF exposure limits are based. The averaging time is a function of the emitter frequency. Therefore, the TWA is weighted over the time derived from AFI 48-109, Table A2.1 (MPEs for upper tier environments) or AFI 48-109, Table A2.2 (MPEs for lower tier environments). The power density value for the MPE must not be exceeded when exposures are more than the time indicated in the tables. For the example above, the averaging time is given as:

$$19.63/f_G^{\ 1.079}$$

Note: f_G is the frequency in GHz (for this example 15,000 MHz = 15 GHz)

The averaging time for this example is:

$$19.63/15^{1.079} = 1.06 \text{ minutes (63.4 seconds)}$$

Total exposure for this scenario is:

$$(304.4\ \text{W/m}^2) \times (90 \text{ sec} / 63.4 \text{ sec}) = 432\ \text{W/m}^2$$

In this case, the individual has been exposed in excess of the MPE, but less than five times the MPE. In accordance with AFI 48-109 and the EMF Base Level Guide, further investigation is not necessary. However, sometimes the situation will dictate additional actions to address shop or individual concerns. In the case of this example, the calculated results are pretty close to five times the limit, and a small fluctuation in exposure time could cause an exceedance of five times the MPE (15 more seconds gives an exposure of 504 W/m^2).

BE may call the EMF Hotline at 1-888-232-ESOH (3764) and discuss the incident with USAFSAM. They can help ensure that there are no steps overlooked and advise on how to proceed. Field EMF measurements may be taken at the location to verify actual levels, which can often be less the calculated levels.

When determining the total exposure, the duration of the exposure must be determined. This can be very tricky, because the time estimates of the potentially exposed person and witnesses can be and usually are exaggerated. Ask the potentially exposed person to repeat their actions and use a stopwatch to get a better idea of actual exposure time. Photographs are a very important part of the investigation. With the transmitter shut down, ask everyone to position themselves exactly as they were during the incident. Then, take photographs from a few different angles.

If the power density at the point of exposure is greater than the measuring capability of the instrument (Narda 8723D, Max Scale= 100 mW/cm2), make multiple measurements starting at 10 mW/cm^2 and move up in increments until the limit is reached. These data can be plotted on a spreadsheet and the actual exposure value can be estimated by extrapolation. Also, USAFSAM has Narda 8715 probes that allow measurements up to 1500 mW/cm2.

Always keep in mind that BE will be viewed as the experts in the situation, and their actions can have significant impact on the outcome of the investigation. They should not show surprise at high level readings or give suppositions about the medical implications of the exposure. It is important that BE personnel remain calm in order to relieve anxieties and fears of those potentially exposed and the witnesses. Be frank, open, confident, and reassuring.

Reporting

Upon completing the medical and field investigations, the potentially exposed person must be advised of the findings and provided a copy of the written report. He/she should receive a complete explanation of the findings and given an opportunity to ask questions regarding their exposure. The attending physician and BE should be available to answer any technical or medical questions during the final briefing of the potentially exposed person.

Regardless of whether the possible exposure is self-reported, reported by others, or calculated by worker monitoring that somehow exceeds time limits and/or planned work boundaries; the incident MUST be reported to the ESOH Service Center. Complete and submit a Department of Defense Tri-Service EMF accident/incident reporting form, per Department of Defense Instruction (DODI) 6055.11, *Protecting Personnel from Electromagnetic Fields*, and AFI 48-109. The final report must be distributed within 45 workdays following the completed investigation and must include all of the information listed in paragraph 4.6.5 of AFI 48-109.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

612. Electromagnetic frequency radiation controls

1. When evaluating EMF controls, what is the concern regarding dummy loads?

2. What controls are specifically required for controlled areas with EMF frequencies below 30 MHz?

613. Investigating potential overexposures to electromagnetic frequency radiation

1. What is the first step of an EMF exposure investigation?

2. If a notification of possible EMF exposure is received, who must complete the initial notifications required by AFOSH STD 48–9?

3. What steps do you take during the exposure reconstruction?

Answers to Self-Test Questions

605

1. 3 kHz to 300 GHz.
2. 100,000 meters to 1 millimeter.
3. Transmitter, transmission line, and antenna.
4. A circular or rectangular hollow metal pipe that conducts EMF by allowing it to reflect off the inner sides of the pipe continually until it reaches the antenna.
5. Continuous wave or pulsed wave.
6. Gain.

606

1. Underwater mobile sonar navigation.
2. In the microwave region.

607

1. "Microwave hearing effect."
2. Indirect.

608

1. Indicate a range of frequencies.
2. Ground-level hazard emitters.

609

1. 9 $mW/cm^{2.}$
2. 0.2 $mW/cm^{2.}$
3. 1 $mW/cm^{2.}$

610

1. 15.85.
2. 0.0009.
3. 90 watts.
4. 0.014.
5. 1.

611

1. Multiply the result by the correction factors found on the probe handle.
2. Pulsed.
3. 360 $mW/cm^{2.}$
4. Worst case under fixed-beam conditions.
5. Extended in front of your body at full arm's length and parallel to the ground.

612

1. They may develop cracks that leak EMF.
2. Electrical safety matting, electrical safety shoes, or other isolation techniques.

613

1. Immediately report the incident to his or her supervisor and seek medical attention within first 72 hours following exposure.
2. BE flight leadership.
3. Interview personnel and witnesses, take photos, measure distances, estimate times at positions, take EMF measurements, and, above all, ensure safety during reconstruction.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to AFCDA.

9. (605) Which component amplifies the electromagnetic frequency (EMF) signal?
   a. Receiver.
   b. Modulator.
   c. Transmitter.
   d. Transmission line.

10. (605) Which component transfers electromagnetic frequency (EMF) energy to the antenna?
    a. Receiver.
    b. Modulator.
    c. Transmitter.
    d. Transmission line.

11. (605) If the wavelength of a radiofrequency radiation (RFR) emission is 20 centimeters (cm), a waveguide designed for it *must* have one dimension that is at least
    a. 5 cm.
    b. 10 cm.
    c. 20 cm.
    d. 40 cm.

12. (606) In what region of the radiofrequency radiation (RFR) spectrum do *most* radar operate?
    a. Infrared.
    b. Microwave.
    c. Low frequency.
    d. Communications.

13. (606) Which is an example of radiofrequency radiation (RFR) emitter found on Air Force bases?
    a. Cathodes.
    b. Scanners.
    c. Laser pointers.
    d. Electronic countermeasures.

14. (607) Which is an example of an indirect effect of radiofrequency radiation (RFR)?
    a. Deoxyribonucleic acid (DNA) damage.
    b. Electronic interference.
    c. Energy reflection.
    d. Tissue heating.

15. (608) Which radiofrequency radiation (RFR) emitter should be the highest priority during the evaluation phase?
    a. Inaccessible.
    b. Short duration.
    c. Climbing hazard.
    d. Ground-level hazard.

16. (608) When evaluating these radiofrequency radiation (RFR) emitters, which repair and maintenance shops should be a higher priority than routine operations?
    a. Inaccessible.
    b. Short duration.
    c. Climbing hazard.
    d. Ground-level hazard.

17. (609) If you need the radiofrequency radiation (RFR) permissible exposure limit (PEL) for radiation workers that have been trained and understand the hazards of exposure, you should look in the table for which environment?
    a. Shielded.
    b. Unshielded.
    c. Upper tier.
    d. Lower tier.

18. (609) Which radiofrequency radiation (RFR) environment would describe the exposure for customers at a golf course near an emitter?
    a. Shielded.
    b. Unshielded.
    c. Upper tier.
    d. Lower tier.

19. (610) What step is *first* in any radiofrequency radiation (RFR) hazard distance calculation?
    a. Solve for the antenna.
    b. Calculate the wavelength.
    c. Determine the average power.
    d. Determine the permissible exposure limit (PEL).

20. (610) Multiplying peak power (in watts) by duty factor (DF) yields the average power for what type of system?
    a. Laser.
    b. Pulsed wave.
    c. Ionizing source.
    d. Continuous wave.

21. (611) What step *must* you take after obtaining radiofrequency radiation (RFR) meter readings in order to find the real power density?
    a. Compensate for temperature.
    b. Multiply by the correction factor.
    c. Account for the calibration curve.
    d. Calculate the time-weighted average.

22. (611) When performing radiofrequency radiation (RFR) measurements, always start
    a. closer to the antenna than the calculated distance.
    b. twice the calculated distance away from the antenna.
    c. further away from the antenna than the calculated distance.
    d. the same area around the antenna as the calculated distance.

23. (611) Where should the surveyor hold the probe while conducting radiofrequency radiation (RFR) measurements?
    a. Above surveyor’s head.
    b. Close to surveyor’s body.
    c. In front of surveyor’s body.
    d. To one side of surveyor’s body.

24. (612) Which radiofrequency radiation (RFR) control is specifically required for upper tier areas where frequencies are below 30 MHz?
    a. Dummy loads.
    b. Wooden fences.
    c. Safety interlocks.
    d. Electrical safety matting.

25. (612) Which type of control is *not* authorized to control radiofrequency radiation (RFR) exposure?
    a. Flashing lights.
    b. Isolation techniques.
    c. Personal protective equipment (PPE).
    d. Posting a qualified technician to observe.

26. (613) At the onset of a radiofrequency radiation (RFR) overexposure investigation, make sure the exposed individual gets a
    a. complete report.
    b. thorough interview.
    c. record of exposure.
    d. medical evaluation.

27. (613) You *must* forward all documentation of radiofrequency radiation (RFR) overexposure investigation to the Air Force Institute for Occupational Health (AFIOH) if the exposures may have exceeded
    a. the permissible exposure limit (PEL).
    b. two times the PEL.
    c. five times the PEL.
    d. ten times the PEL.

Please read the unit menu for unit 3 and continue ➔

Unit 3. Lasers

LIGHT AMPLIFICATION BY THE stimulated emission of radiation (laser) has excited human imagination for many years. When the first lasers were developed in the early 1960s, they were more curiosities than useful tools. It was often joked that the laser was a solution looking for a problem, but it did not take long to find uses for it. Today, these devices are used in a wide variety of applications, and with their proliferation have also come increased risk to more and more people. Lasers are at work in compact disc players, survey instruments, laser printers, and bar code readers. Industrial uses include cutting, drilling, welding, heat-treating, marking, measuring, communicating, and nondestructive testing. A laser can cut (or more accurately "burn") very finely and drill extremely small holes quickly. These same attributes make it ideal for medical use in bloodless surgery, particularly for procedures that require very precise work, such as eye surgery. This unit introduces basic laser fundamentals, hazard classifications, biological effects, hazard evaluation, exposure limits, and controls. A good grasp of these topics is needed to understand the health risk and recognize potential hazards as a BE journeyman. An advanced course on lasers and laser protection is needed to be a laser safety officer (LSO). Knowledge of laser beam characteristics, as well as how beams are produced, can give some insight into why they are so useful and potentially hazardous. Being familiar with the fundamental principles of laser energy and the components of a laser system will help with fully understanding laser hazards.

614. Laser fundamentals

As discussed in the overview of radiation in a previous unit of this volume, laser radiation is a type of EM radiation created in the infrared (IR), visible, and UV portions of the EM spectrum (fig. 3–1).

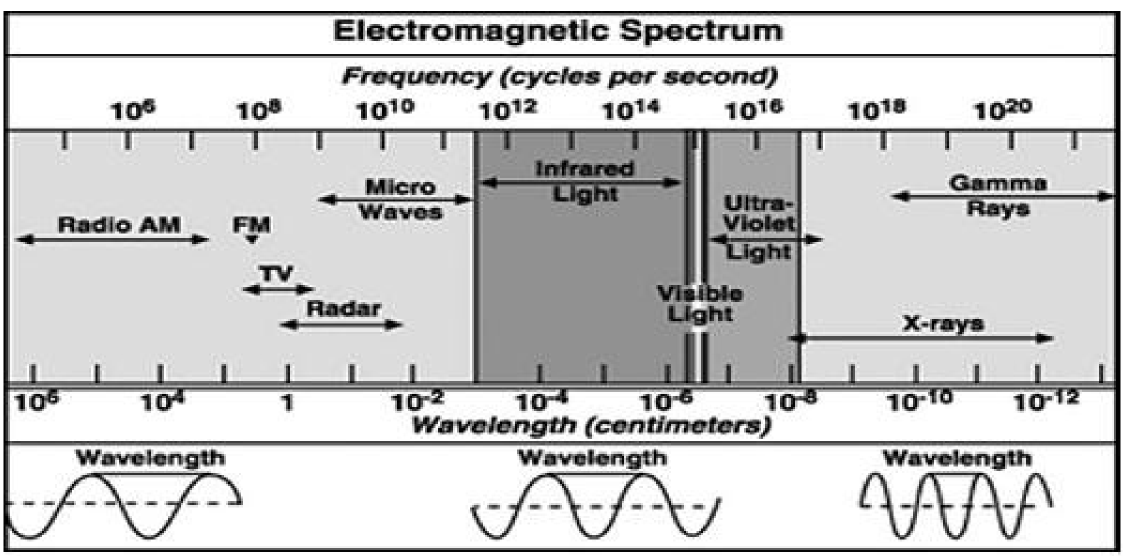

Figure 3–1. Laser radiation spans the IR, visible, and UV wavelength regions.

The EM part of the spectrum includes other types of light as well, but there are two characteristics of laser energy that make it unique from other types of light. The first is that the beam of light emitting from a laser is collimated (i.e., directional). This means that the laser beam is emitted as a tight column of light that does not spread out, or "diverge" much as it travels away from its source. The beam of a flashlight is not collimated like a laser and its photons travel in paths that diverge quickly as they radiate away from their source, this is why the beam gets wider and wider as it travels farther from the flashlight (fig. 3–2). While laser light does have some divergence, it is much less noticeable than a standard light beam and, since all the photons travel in the same direction, is considered collimated light.

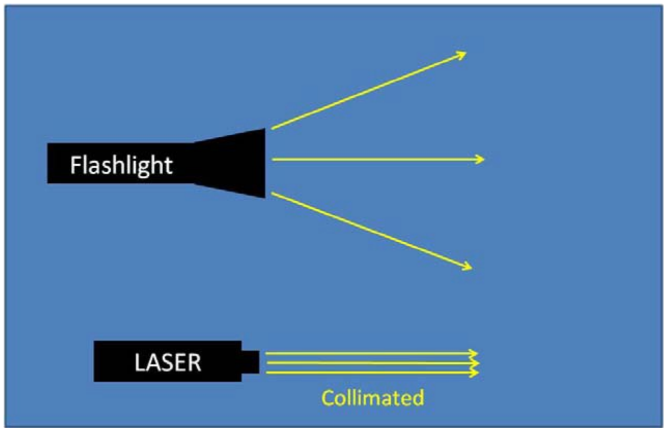

Figure 3–2. Standard vs. collimated light beam.

The second unique characteristic of laser energy is that the beam of light emitting from a laser is coherent. Coherency means that all EM waves are the same wavelength (i.e. all wave "crests" and "troughs" are aligned). While most light sources emit light of many different wavelengths that mix and interfere with each other, lasers emit coherent light beams of a single wavelength that do not interfere with each other (fig. 3–3). This also causes the light emitted from a laser to be monochromactic (i.e., one color).

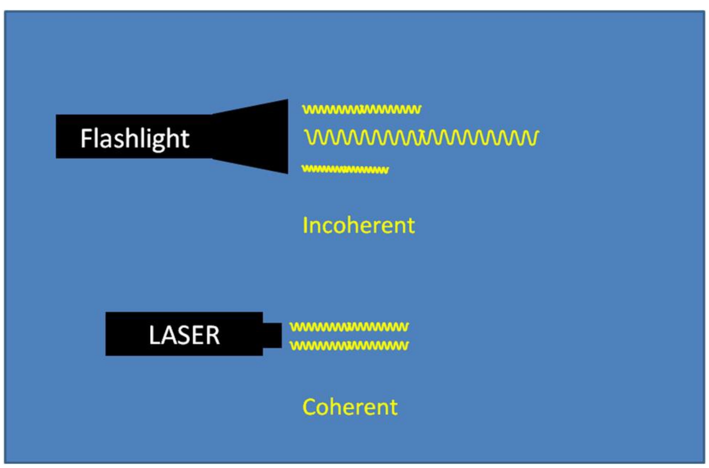

Figure 3–3. Standard vs. coherent light beams.

Similar to EMF radiation, the light emitted from a laser can be either as a continuous or pulsed wave of energy. Unlike EMF, however, the classification of continuous wave lasers includes those with long pulses that tend to act as continuous waves to the eye. A pulse width or pulse duration longer than or equal to 0.25 seconds is still considered a continuous wave laser. If the pulse is shorter, the laser is considered a pulsed laser. The pulse repetition frequency is the number of pulses per second—expressed in hertz.

Laser operation

All lasers have three basic components: the pumping system, the laser medium, and the optical cavity (fig. 3–4).

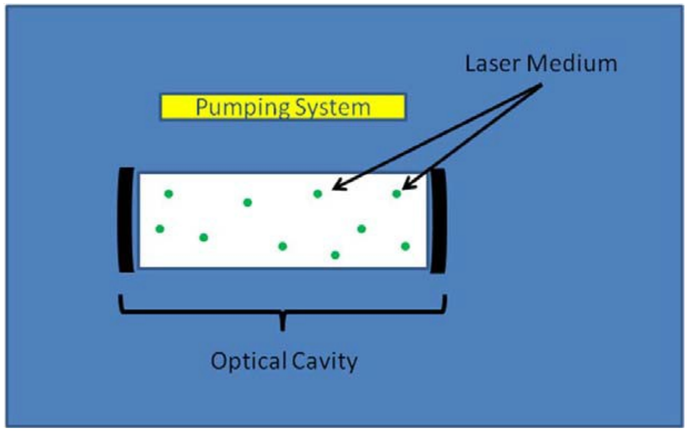

Figure 3–4. Laser components.

The pumping system is the means of getting energy into the laser medium to excite electrons that emit the photons that make up the laser beam. Some pumping systems use a strong light source while others use electric currents, chemical reactions, and even other lasers. The laser medium is made up of atoms or molecules of a specific material that has useful characteristics when its electrons are excited by an energy pump. When energy from the pumping source interacts with the laser medium, it stimulates photon emissions of a specific wavelength that travel in the same direction and in phase with other photons (fig. 3–5). This is done in an optical cavity that reflects the photons back and forth between two mirrors. The photons reflect between the two mirrors, quickly building into an amplified beam of energy that is eventually released from the optical cavity.

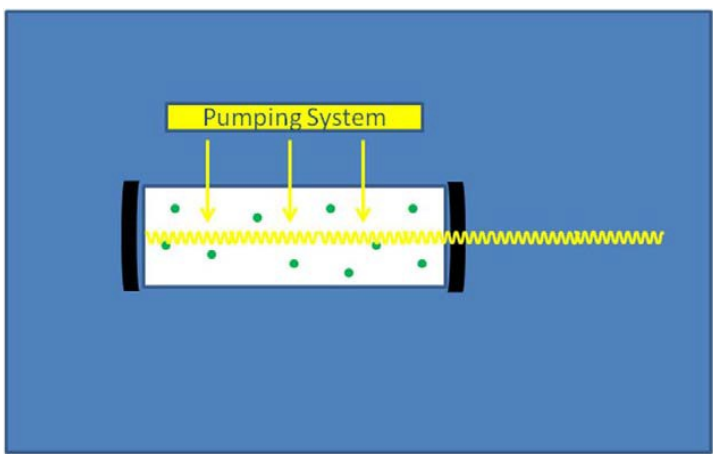

Figure 3–5. Laser beam created in optical cavity.

Laser classifications

The classification scheme adopted by the Air Force is American National Standards Institute (ANSI) Z136.1, *American National Standard for Safe Use of Lasers*. This standard is based on laser power and accessibility to the beam during operation. There are other laser classification standards available, such as the Food and Drug Administration system. Just be aware that ANSI Z136.1 is adopted by the Air Force in AFI 48–139, *Laser and Optical Radiation Protection Program*, and ANSI Z136.1 has information on how to relate other classification systems to the ANSI system.

BE team members are not be required to classify lasers; the primary BE role regarding a laser is to understand the classification scheme in order to evaluate the safe operation of the laser or laser system. Due to the complex nature of classifying a laser or laser system, only personnel trained in laser safety, optical engineering, or physics are suited to perform the detailed hazard evaluation computations or classification determinations. Lasers without a classification are rare at Air Force bases, but if encountered, contact the USAFSAM for assistance (1-888-232-ESOH [3764] or esoh.service.center@wpafb.af.mil).

Lasers are grouped into categories or "classes" requiring similar control measures, primarily based on their capability to injure people and causing fires. The classification scheme developed by ANSI separates lasers into classes based on the relative hazard of each laser. Class 1 lasers are the least hazardous and Class 4 lasers are the most hazardous.

Class 1 lasers

A Class 1 laser is any laser system containing a laser that cannot emit laser radiation at levels that are known to cause eye or skin injury during *normal* operation. Lasers can be Class 1 because they are very low power or because the beam is fully enclosed. The operators of Class 1 lasers do not need to take any precautions to protect themselves from laser hazards. All required protection is built into the laser system. Class 1 lasers are exempt from control measures and other forms of surveillance. A laser normally classified as Class 3 or 4 may be classified as Class 1 if it is embedded into the components of another system. If, however, the component in which the laser is embedded is opened for maintenance (e.g., during alignment or servicing), then the maintenance personnel are subject to the higher-class controls.

Class 1M lasers

A Class 1M laser is a sub-classification of the Class 1 laser in which the laser is considered incapable of producing hazardous exposure unless viewed with an optical instrument, such as binoculars. Class 1M lasers are exempt from control measures, other than to prevent potentially hazardous optical aided viewing, and other forms of surveillance. Laser training is required per AFI 48–139, Section 2.20.8.

Class 2 lasers

Class 2 lasers are low-power lasers that emit energy in the visible range (400-700 nm wavelengths) above class 1 limits but less than class 3 limits. Class 2 lasers are not considered strong enough to damage a person's eyes because of the normal human aversion response (a person will normally blink and/or look away). However, these lasers may not be safe for a person who deliberately stares into the laser beam for longer than 0.25 seconds.

Class 2M lasers

Class 2M lasers are a subclass of Class 2 lasers, and similar to the Class 1/Class 1M relationship, they are low-power visible lasers that are potentially hazardous if viewed with collecting optics. A Class 2M laser power can exceed a Class 2 level; however, the beam is either highly divergent or the beam diameter is large so that only a small proportion of the light enters the eye. Laser training is required per AFI 48–139, Section 2.20.8.

Class 3 lasers

Class 3 lasers are intermediate-power lasers, which may be hazardous under direct and "specular reflection" viewing conditions. The term specular refers to the type of reflection from a mirror or shiny/glossy surface (fig. 3–6). The beam does not significantly diverge or spread from this type of reflection. A diffuse reflection is where the beam is not reflected intact, does not remain collimated, and the power becomes spread over distance. A diffuse reflection is not usually a hazard for Class 3 lasers.

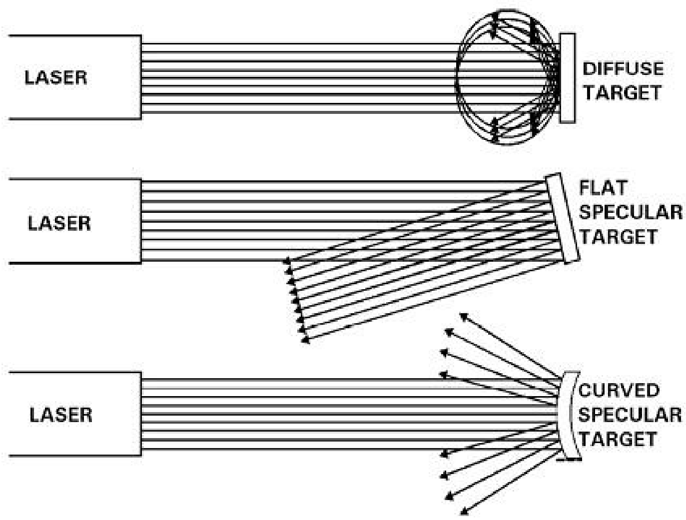

Figure 3–6. Diffuse and specular reflections.

Class 3R lasers

Class 3R lasers are a subclass of Class 3 lasers that may be hazardous under some direct and specular reflection viewing conditions if the eye is appropriately focused and stable. The probability of an actual injury from these lasers is small. They do not present a fire or diffuse reflection hazard but may present a hazard if viewed using an optical instrument. Training, standard operating procedures (SOP), and alignment procedures shall be provided for laser operators, maintenance, and service personnel using Class 3R lasers.

Class 3B lasers

Class 3B lasers are a subclass of class 3 lasers which may be hazardous under direct and specular reflection viewing conditions. They are not normally a fire hazard, and diffuse viewing is not normally a hazard unless done under conditions of intentional staring within the diffuse hazard distance. Specific controls must be in place to operate a class 3B laser. All personnel operating Class 3B lasers or laser systems must complete training before use. Eyewear is required for all Class 3B unenclosed laser use.

Class 4 lasers

Class 4 lasers are high-power lasers which are hazardous to view under any condition (e.g., direct beam, specular reflections, or diffusely scattered) and are a potential skin and fire hazard. Class 4 lasers include all lasers in excess of Class 3B limitations. This laser class can also produce laser-generated air contaminants and potentially hazardous laser plasma radiation. Specific controls must be in place to operate a class 4 laser. All personnel operating such a laser or laser system must complete training before use.

It is important to know these laser classifications in order to easily recognize potential hazards and ensure people are adequately protected from the effects.

615. Biological effects of lasers

Lasers are electromagnetic radiation, primarily in the IR, visible, and UV portions of the spectrum. Although burns and skin damage are possible, the main health concern in these wavelengths is damage to the eye. As would be expected, the human eye effectively collects and focuses visible light, enabling sight. Unfortunately, the great amount of energy in a laser beam at these wavelengths can literally burn eye structures, creating damage and blindness. The IR and UV bands cannot be seen, but they are close enough to visible light for the eye to collect and focus the energy causing damage.

The most common cause of laser-induced tissue injury is thermal injury, which occurs because of a rise in temperature following energy absorption. The main hazard is to the eye, but with sufficient laser power, skin burns can also occur. In addition to these thermal effects, a laser beam can also create a photochemical (photons stimulate a chemical reaction) change in the eye that can result in permanent blindness.

Eyes

Human eyes focus visible light from the environment and convert the energy into what the brain interprets as vision. Most of the light in the environment lacks enough power to cause immediate damage, with a few exceptions (such as looking directly at the sun, welding operations, etc.). Because of the high degree of beam collimation, a laser serves as an ideal point source of intense light. Similar to direct viewing of the sun, the eye can focus the beams from visible and near visible lasers which will damage the eye. A review of the eye structures, pointing out the portions that are most involved with laser injury will help to understand the potential biological effects of lasers.

As indicated in figure 3–7, at the front of the eye is a tough layered membrane called the cornea. It is a powerful refracting surface, providing two-thirds of the eye's focusing power and allows visible light to enter the interior of the eye. Most of the energy in the visible light portion of the spectrum passes through the cornea, but the cornea will absorb the energy from far UV and far IR wavelengths. When the cornea absorbs energy faster than it can dissipate it, damage occurs.

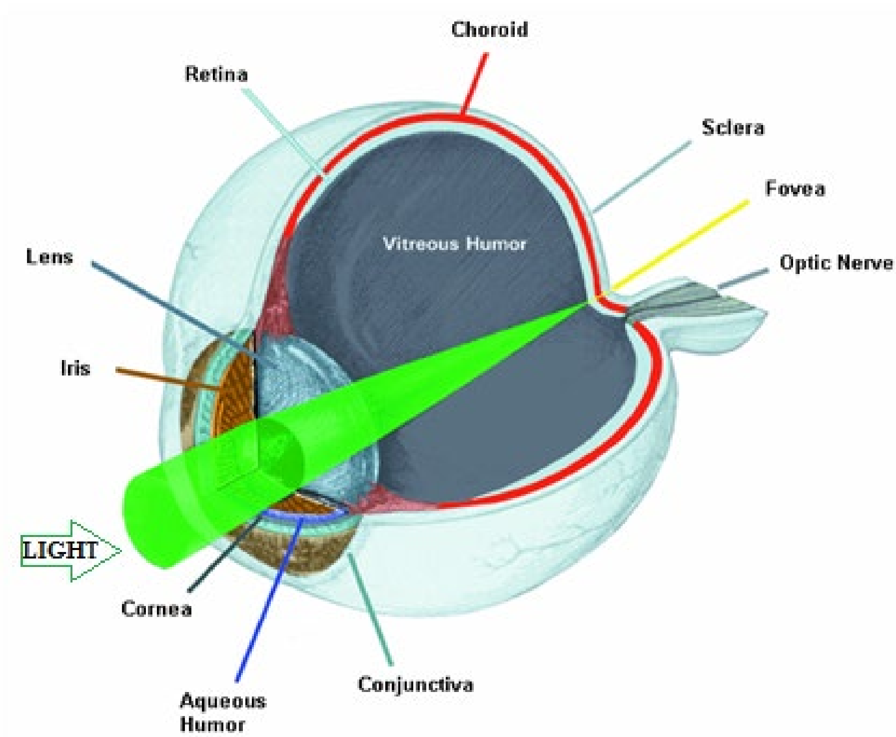

Figure 3–7. Human eye diagram.

The lens continues focusing the light energy into a small area on the retina. The retina in the back of the eye is where the image is projected. It contains millions of photoreceptors that capture light rays and convert them into electrical impulses. The macula lutea is a small part of the retina that enables detailed central vision. In its center is the fovea, the area of greatest visual acuity in the eye. The retina is connected to the brain by the optic nerve. Signals generated in the retina are transmitted by the optic nerve to the brain, which interprets these signals as vision. Finally, the choroid contains layers of blood vessels that supply blood to the back of the eye.

There is a potential for damage to each of these structures. The specific type or location of damage depends on the power (energy that is deposited over time) and wavelength of the laser, as illustrated in figure 3–8.

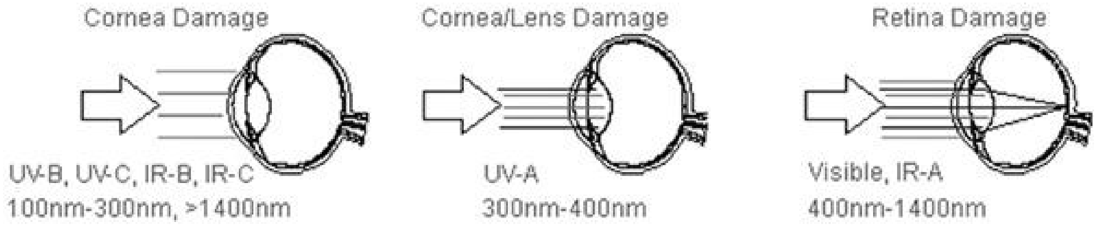

Figure 3–8. Eye damage by varying laser wavelengths.

Far UV wavelength (<300 nm) damages the cornea by the same photochemical mechanism as bright sunlight. The damage causes keratoconjunctivitis (often called welders flash or snow blindness) and preferentially affects the outer layers of the cornea. There is usually a latent period of several hours before effects are felt. The cornea has nerve endings; therefore, effects can be very painful and debilitating, but the cornea will generally self-repair within a few days.

Far IR wavelength (>1,400 nm) also damages the cornea, but from thermal damage that occurs throughout all layers of the cornea. At high enough energy deposition, opacities occur and damage is permanent. These opacities are referred to as laser cataracts.

Near UV wavelengths (between 300 and 400 nm) are primarily absorbed in the eye lens, but also deposit energy in the aqueous humor, iris, and vitreous humor (refer to fig. 3–7). Long-term UV exposure can cause cataract formation on the lens.

Visible and near IR wavelengths (between 400 nm and 1,400 nm) are focused onto the retina. In this range, the focal magnification (optical gain) of the eye increases the laser power density, so these lasers don't require as much power to cause damage. Retinal burns or thermal burns (lesions) in the eye are caused when the eye cannot regulate the heat loading of the retina. Secondary bleeding into the vitreous humor may occur as a result of burns that damage blood vessels. This bleeding can obscure vision well beyond the area of the lesion. Although the retina can repair minor damage, major injury to the macular region of the retina may result in temporary or permanent loss of visual acuity or blindness.

The duration of exposure is important because it limits the amount of energy that can be deposited, thus reducing tissue damage. The aversion response often enables the eye to protect itself. This holds true for Class 1 and 2 lasers; they do not normally present a retinal hazard. Unfortunately, intrabeam or specular reflection viewing of class 3R (high power units only), 3B, or 4 lasers and even diffuse reflections from class 4 lasers may cause an injury before the aversion response can protect the eye.

For pulsed lasers, the pulse duration also affects the potential for thermo mechanical eye injury that is caused by rapidly heating of the tissue with short pulse durations. Pulses less than one millisecond in duration focused on the retina can cause substantial damage and bleeding in addition to thermal injury. Many pulsed lasers now have a pulse duration less than one picosecond (i.e., one trillionth of a second).

For laser radiation, the permanent hazards to the eye typically overshadow those to the skin which are often temporary. Nonetheless, it's important to prevent even temporary skin damage.

Skin

The skin is susceptible to sunburn effects from ultraviolet wavelengths and thermal burns from visible and infrared wavelengths. The severity can range from mild redness (i.e., erythema) to blistering and charring. High levels of irradiance can even cause small areas of tissue exposed to the beam to vaporize. The skin reflects, absorbs, and transmits laser radiation in different percentages that depend upon the characteristics of the skin and the wavelength involved, as illustrated in the table below.

Spectral Division	Spectral Range (nm)	Skin
UV-C	100–280	Erythema
UV-B	280–315	Erythema Accelerated aging Cancer
UV-A	315–400	Pigment darkening Photosensitivity Burns
Visible	400–770	Photosensitivity Burns
IR-A	770–1400	Burns
IR-B	1400–3000	Burns
IR-C	3000- 10^6	Burns

Understanding how lasers interact with the eye and skin allows anticipation and recognition of where laser hazards may exist.

Ancillary hazards

In addition to direct hazards to the eyes and skin associated with exposure to lasers, it is also important to note other non-beam hazards associated with the use of lasers. The non-beam hazards, in some cases, can be more severe than the laser beam hazards and even life threatening (e.g., electrocution). The non-beam hazards (or ancillary hazards) include:

- Electrical hazards caused by the high voltage used to operate some lasers.
- Fire or explosion caused by the laser beam.
- Laser-generated air contaminants.
- Ionizing and non-ionizing radiation.
- Compressed gases.

A more comprehensive listing and explanation of ancillary hazards is identified in the USAFSAM *Technical Guide to Lasers and Optical Radiation* (AFRL–SA–WP–SR–2013–0011). Most of these hazards are health hazards BE personnel are prepared to evaluate and control, but some may require support from ground safety and civil engineering experts as well. Understanding the biological effects of lasers, the hazards laser beams can create, and the non-beam ancillary hazards associated with laser systems, allows identification and analysis of laser hazards.

616. Identifying/analyzing laser sources and hazards

Lasers are used in a wide variety of operations and locations on typical AF installations. Industrial laser use includes cutting, drilling, welding, heat-treating, marking, measurement, communications, and nondestructive testing (fig. 3–9). Lasers are used in medical treatment facilities for surgery, particularly for procedures that require very precise work such as eye surgery. Lasers are also used in military systems such as target designators, night vision illuminators, bore sights, and rangefinders that may be used by organizations outside of the typical industrial workplaces BE personnel routinely survey.

Figure 3–9. Example industrial laser system.

Identifying lasers

Laser systems at established installations have already been identified and associated with many workplaces. Existing laser systems information should be available in the DOEHRS radiation module. If new laser systems have not yet been identified or evaluated, use the pick lists to see the kinds of laser systems that may be present to get an idea of where site reconnaissance for laser systems and hazards may be valuable.

Another great source of information to identify laser systems and hazards is the USAFSAM Environment, Safety, and Occupational Health (ESOH) Service Center Laser Homepage (https://hpws.afrl.af.mil/dhp/OE/ESOHSC/index.cfm). The laser homepage has a wide range of laser survey reports that cover laser systems in all types of AF operations, including medical, research, training, civil engineering, and many other operations. These reports can help identify where lasers may be used, as well as assist in subsequent evaluation of the systems. The USAFSAM ESOH Service Center can also provide a list of military laser systems that may be used.

Laser hazard evaluation

The hazard evaluation of a laser operation is often done in concert with adding new lasers to the installation laser inventory or shop surveys. According to AFI 48–139 and ANSI Z136.1, a laser hazard evaluation must occur before the start of laser operations involving Class 3B, Class 4, and military specific lasers. Class 1 and 2 lasers are not typically evaluated because they are not powerful enough to create a hazard under normal circumstances. It always makes sense, though, to confirm those circumstances are true, especially for enclosed Class 3 and 4 lasers that have been reclassified by the LSO as Class 1 due to engineered controls.

Consider laser system operational aspects

Three primary aspects of laser operations influence the hazard evaluation:

1. The laser or laser system's capability to cause injury (i.e., laser class).
2. The environment in which the laser is used, including access to the beam path.
3. The personnel who operate or populations at risk who may be exposed to laser radiation.

Laser system capability to cause injury

Capability to cause injury is established by the laser classification. When performing a laser hazard evaluation, consider the following questions:

- What is the laser manufacturer's hazard classification?
- Has the laser system been altered?
- Does the manufacturer hazard classification still apply in its current configuration?

The LSO has the authority to reclassify a laser system's hazard class if controls prevent exposure during normal operations. Check that no user modifications have been made that might defeat or bypass an engineered control that was used by the LSO to justify downgrading the hazard classification.

Environment in which the laser is used

The environment in which the laser is used may vary with each laser application. It is extremely important that the environment in which the laser is used be considered in order to determine whether control measures are necessary and/or adequate.

When performing a laser hazard evaluation, some typical questions that should be considered during the evaluation include:

- How is the laser being used?
- Are optics in use (e.g., lenses, microscopes, optical fibers)?
- Is the beam path fixed?
- Are specularly reflecting objects in or near the beam path fixed?

Collect information on how and where the laser is used, potential orientations of the laser beam, and surfaces within the workplace/areas of concern (AOC) that might cause beam reflections. Gather information on ancillary hazards associated with the laser system, such as laser generated air contaminants from cutting and etching processes, compressed gas used with the laser system, or ionizing radiation emitted by the system. Often information on ancillary hazards can be found in the laser system's commercial operating manual or military technical order.

Personnel exposed and/or populations at risk

When performing a laser hazard evaluation, some typical questions that should be considered during the evaluation include:

- What are the potential exposures and who is potentially exposed?
  - Consider both beam and non-beam hazards.
- What is the probability of the presence of uninformed, unprotected transient personnel?

Gather information on existing controls in the workplace/AOC, such as laser safety glasses provided by the manufacturer, interlocks designed into the system, labels, signs, and other control measures. Site reconnaissance is an opportunity to confirm data on laser systems and if documentation of their use in the workplace/AOC is current and accurate for laser systems that have been previously identified and evaluated.

It may help to follow the occupational and environmental health site assessment process to assist with identification of laser hazard exposure pathways needing further assessment. Consider personnel who may have exposure under abnormal conditions (e.g., laser maintenance workers, transient workers entering a restricted area) when determining populations at risk of exposure to laser hazards. Also consider non-beam hazards (e.g., laser generated air contaminants).

After carefully considering each of the three aspects of laser system operations, specific information about the laser system will be needed to continue the hazard evaluation.

Gather laser system information

Guidance will normally be given by the installation's LSO, typically a senior BE officer or noncommissioned officer (NCO), on what specific information to collect for a laser system. In a deployed location without senior BE personnel, USAFSAM consultants can provide guidance on how to collect the appropriate laser system parameters. Some of the laser parameter information needed includes manufacturer, model number, military designation, wavelength, exposure time, pulse mode/parameters, beam profile/distribution/geometry, location, and laser class. When collecting information on a laser system, be aware that it may have several "operating modes" with different wavelengths, pulse parameters, and so forth. Since these parameters affect the overall hazard evaluation and risk assessment for the system, it is critical to gather information on all potential system output parameters.

Several items of information are needed to complete a hazard evaluation, and are typically obtained from the users of the laser:

- Laser specifications sheets.
- SOPs that include alignment procedures and all elements required by ANSI Z136.1.
- A form detailing what laser eyewear is planned for the operation (The ESOH Service Center Webpage provides an example of and project eyewear form that can be used).
- Any project technical specifications/orders that outline the scope of the laser project should also be sent in to assist the unit laser safety officer (ULSO) and/or installation laser safety officer (ILSO) to understand the scope of laser use.
- Any maintenance/servicing procedures needed.
- A timetable for plan start-up and operation (This should include range scheduling where possible).

The nominal hazard zone (NHZ) associated with Class 3B and Class 4 lasers shall also be determined. The NHZ will be discussed later.

Assess with laser hazard analysis software

The assessment of laser beam hazards can be a complex task and is normally accomplished by a qualified LSO. Unlike with EMF, BE personnel do not have equipment to measure laser power and help determine hazards. Therefore, theoretical calculations are necessary for laser evaluations. Fortunately, there is a tool that will help associate the parameters and health risks. This tool is the Laser Hazard Analysis Software (LHAZ).

LHAZ combines a MPE calculator and ANSI classification routine (fig. 3–10) with hazard assessment and range equations worksheets to make laser safety assessment and hazard control easier.

NOTE: LHAZ is not an expert system. It is not a replacement for a knowledgeable LSO. It is only a tool to help LSOs in the performance of their duties.

The LHAZ program requires input of the laser parameters collected during site reconnaissance. Wavelength and power are key factors, along with whether the laser is pulsed (and the pulse parameters) or continuous wave, and the beam diameter and divergence.

Given these parameters, along with additional information about the how and where the beam or reflections could be viewed, LHAZ will show hazard information, such as laser class, MPE, nominal ocular hazard distance (NOHD), and NHZ for the laser (fig. 3–11).

Using the output from LHAZ, BE personnel can assess risks in the workplace/AOC and recommend control measures.

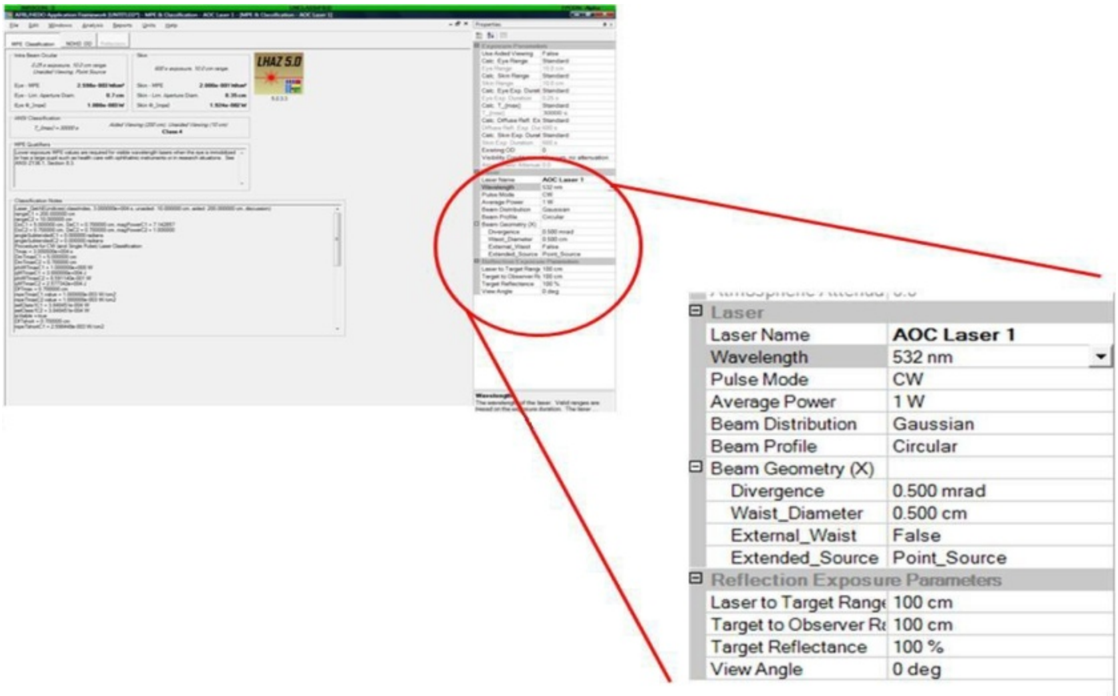

Figure 3–10. Laser system information needed for LHAZ.

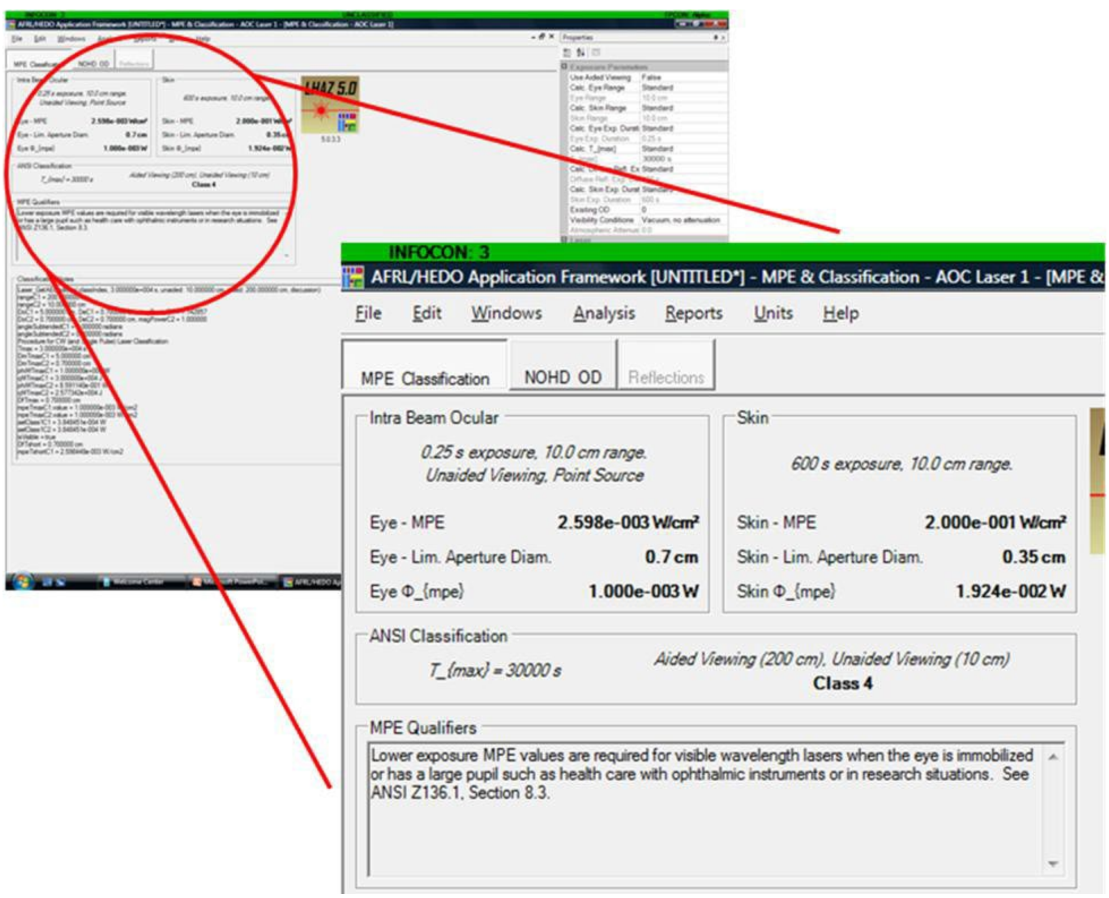

Figure 3–11. Example LHAZ output data.

It is important to periodically review the laser system parameters, the operations involving the laser system, and the control measures protecting workers from the laser hazards. Changes in any one of these items can affect the overall health risk assessment for the laser system.

Keep in mind also that AFI 48–139 outlines some specific requirements for different types of laser uses:

- For visible lasers used in an outdoor environment, the hazard evaluation should include determining ranges associated with visual interference levels using ANSI Z136.6, *Safe Use of Lasers Outdoors*.
- For broadband optical radiation hazards, threshold level values (TLV) as listed in the American Conference of Governmental Industrial Hygienists (AGCIH) TLV guidelines shall not be exceeded.
- For directed energy weapons, AFI 91–401, *Directed Energy System Safety*, shall be followed.

617. Maximum permissible exposure limits and nominal hazard zones for lasers

This lesson will briefly address maximum exposure limits, ocular hazard distance, and hazard zone for lasers.

Maximum permissible exposures

Similar to EMF hazards, laser hazards are evaluated against a MPE. The MPE defines the level of laser radiation to which a person may be exposed without hazardous effects or adverse biological changes in the eye or skin. MPEs are established by ANSI STD Z136.1 and have been adopted by AFI 48–139. MPEs depend on wavelength, exposure duration, output (continuous wave or pulse), and exposure conditions. There are two types of MPEs: ocular MPEs to prevent eye damage, and skin MPEs to protect the skin. The eye MPEs are generally lower than skin MPEs, which makes sense because the eye is generally much more sensitive to laser energy than the skin.

Nominal ocular hazard distance

Because laser energy slowly decreases with distance from the laser source, the energy of the laser beam will eventually fall to levels that are below the ocular MPE. The distance from the laser to where this occurs is called the NOHD. In some cases where the laser beam has nothing to interrupt its travel, the NOHD defines the boundaries of the NHZ (fig. 3–12).

Nominal hazard zone

The NHZ is the space within which the level of the direct, reflected, or scattered radiation during normal operation exceeds the applicable MPE. Indoors, the NHZ is often limited by walls and ceilings that confine the laser beam within the room the laser is used. For outdoor operations, the NHZ may be limited somewhat by terrain, but can extend miles in any direction that the laser can be expected to aim its beam. Exposure levels beyond the boundary of the NHZ are below the appropriate MPE level.

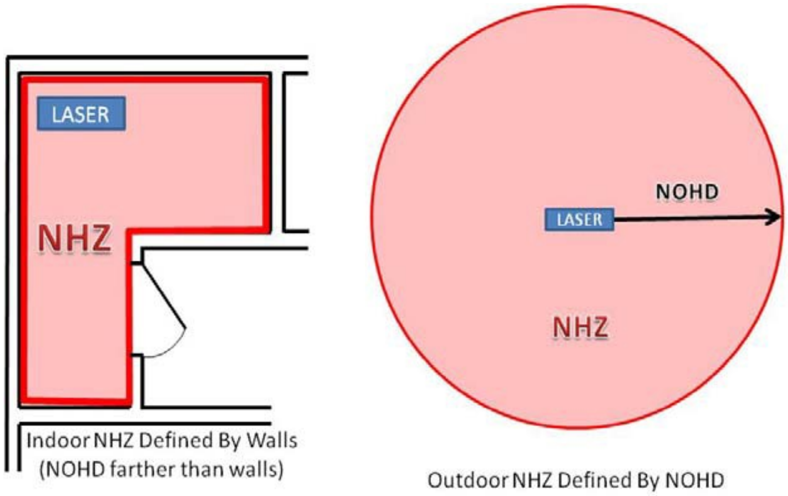

Figure 3–12. Example indoor and outdoor NHZ.

It is important to realize that external magnification (such as binoculars) can affect the NOHD and NHZ. The term aided viewing is used to explain optical magnification that may be used. In the military, it is likely that people will use binoculars or other optical aids in the vicinity of a laser (lasers are found in range finders, illuminators, and target designators used by the military). If someone were to view this laser energy through optical aids, the laser energy that otherwise may not have been a hazard is now more focused and, therefore, more hazardous to the eye.

618. Laser controls

Similar to other hazard types, control measures for laser hazards are used to reduce the risk of exposure to the eyes and skin from hazardous laser radiation levels, as well as to reduce the risk from non-beam hazards associated with laser operations. AFI 48–139 identifies control measures for defined laser hazards but recommends that BE personnel use ANSI Z136.1 as a guide for developing appropriate control measures. The ANSI Z136.1 standard discusses general classes of control measures—engineering controls, administrative and procedural controls, and protective equipment.

Engineering controls

There is a wide variety of engineering control measures identified by ANSI to control laser hazards. Protective housings are one type, where the potentially hazardous laser beam is contained within a barrier specifically designed to house the laser system. Protective housings are generally the size of the system itself but can be large enough to walk into and are often combined with other engineering controls to prevent exposure if the housing is removed or accessed. Key controls, which only allow the laser to be activated when a key is inserted, and interlocks, which disable the laser when potentially hazardous areas are accessed, are other types of engineering controls. Viewing windows and diffuse display screens are engineering controls that allow user visibility for certain laser operations but prevent exposure above the MPE.

The ANSI Z136.1 standard details equipment labels, warning signs (fig. 3–13), visible or audible warning systems (e.g., lights, sirens), laser controlled areas, and many other methods to control laser hazards.

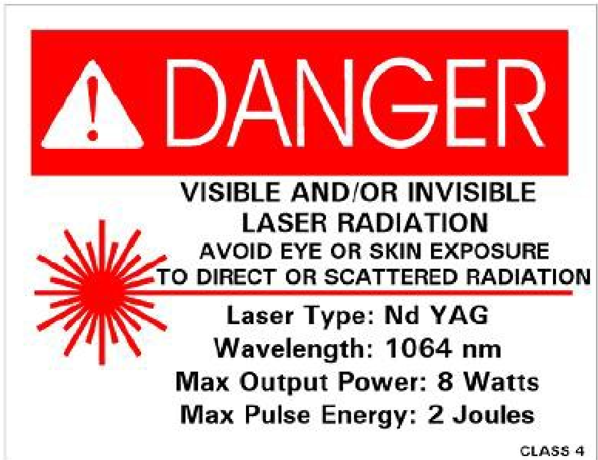

Figure 3–13. Example warning sign.

Administrative and procedural controls

As with many other health hazards, engineering controls may not be sufficient to control laser radiation hazards in all cases, so ANSI defines a wide range of administrative and procedural control measures that can be used to augment engineering controls. Some examples include standard operating procedures for users to follow for safe operations and special attention to alignment procedures, where many exposure incidents typically occur. Safety training is also identified as an administrative control, including training operators, LSOs, and service/maintenance personnel.

Protective equipment

Like all other health hazards, personal protective equipment is the last choice for controlling laser hazards, but in some cases where engineering and administrative controls are not sufficient, it must be used. Since the eye is generally the most susceptible part of the body to laser radiation, it is easy to see why protective eyewear is the most common type of laser protective equipment. Laser protective eyewear, including goggles and glasses, is designed to attenuate the laser energy to levels below the MPE by the time the laser beam contacts the eye, while allowing the operator to see through the eyewear.

The ability to reduce laser energy as it passes through protective eyewear material is called the optical density (OD) of the eyewear. The OD of material is often highly dependent on the wavelength of the laser energy passing through the material. Laser protective eyewear is based on an OD at particular wavelengths (such as the specific output wavelengths of the laser system the eyewear supports) or a range of wavelengths. This information is typically etched into the protective eyewear lens material to ensure the appropriate protection is provided for the laser output wavelength(s). When reviewing laser protective equipment at a workplace/AOC, BE personnel need to pay attention to the OD and wavelength information etched into protective eyewear.

To evaluate laser protective eyewear for adequacy, simply compare the laser wavelength and the LHAZ calculated OD to the specifications of the eyewear. There are two calculated OD fields listed in LHAZ: Max Additional OD and Additional OD Required (At Range) (fig. 3–14). In most cases, the result labeled "Additional OD Required (At Range)"is used because it determines how much of the energy can actually enter the pupil of the eye. If the laser protective eyewear has an OD less than the OD required for a specific wavelength, the eyewear will not block enough laser energy and alternate protective eyewear with a suitable OD for that wavelength is recommended.

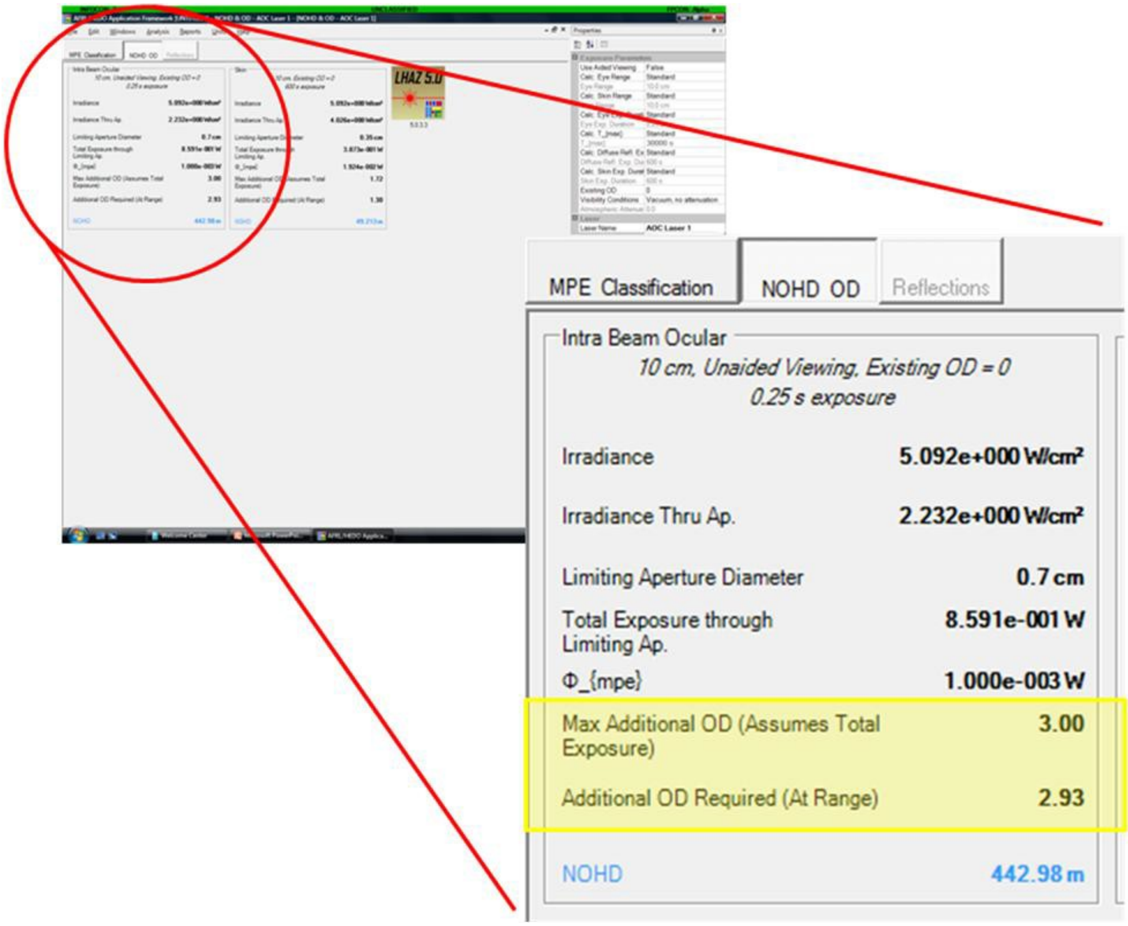

Figure 3–14. Example ocular density information from LHAZ.

Controlling the use of optics (such as binoculars) may also be necessary for laser eye protection. This is most common on munitions ranges where lasers may be used for targeting or illumination. Optics, if used, must be evaluated as part of the laser system. Be aware that the use of optics can significantly affect the NHZ and NOHD, subsequently requiring further controls. Some magnifying optics may be purchased with OD for given power/wavelengths.

Protective equipment can also include skin protection. If engineering controls are not sufficient in protecting the skin, then skin covers and/or creams for UV exposure are recommended by ANSI. Most gloves will provide some protection against laser radiation. Tightly woven fabrics and opaque gloves provide the best protection. A laboratory jacket or coat can provide protect the arms. For Class 4 lasers, consideration shall be given to flame-retardant materials.

ANSI Z136.1 Table 10 lists engineering, administrative and procedural, and protective equipment controls recommended by ANSI for each laser classification. The table below is an example of the type of information found.

Engineering Control Measures	Laser Classification						
	1	1M	2	2M	3R	3B	4
Protective Housing	X	X	X	X	X	X	X
Interlocks	*	*	*	*	*	X	X
Key Control							X
Indoor Laser Controlled Area						X	X

*Shall use if enclosed laser is Class 3B or Class 4

619. Investigate potential laser overexposures or accidents

The ultimate goal of a laser safety program is to minimize laser exposures and ensure personnel are not exposed to laser radiation but occasionally accidents or incidents occur. Any accident/incident involving a suspected laser, broadband or other optical radiation overexposure, visible laser illumination that negatively impacts mission operations or a laser exposure causing material damage to personnel, AF equipment, systems or sensors shall be investigated and documented. Laser accidents or incidents could involve exposures to the direct beam and the reflected beam as well as a number of non-beam exposures such as fires, electrocution, and shock. When any type laser accident or incident occurs, specific and prompt steps must be taken by the ILSO, medical providers, and the individual's chain of command to protect individual(s) and other resources exposed as well as prevent further exposures. The installation commander delegates authority to the ILSO to suspend laser operations that pose a significant health risk to personnel. The basic steps to be taken following a laser overexposure or accident include the following:

- Seek medical care for the individual(s) exposed.
- Notify all key personnel.
- Conduct investigation.
- Document and report findings.

Medical care

The first step in a laser exposure response scenario is to seek medical care without delay for the individual(s) exposed. This is extremely important since the length of time between exposure and treatment can often change the outcome, and shortening the time reduces the chance of negative long-term effects. Although a military treatment facility (MTF) is preferred, it is not required. Exposed individuals should seek medical care at the closest MTF; however, if the individual is not being cared for at an AF MTF, the host AF MTF is required to make sure an AF physician contacts the attending physician immediately to coordinate required medical examinations and treatments. Aircrew or other operational personnel who receive a laser exposure from friendly or hostile sources should report to the flight surgeon's office (FSO) or their squadron medical element if available.

Notify key personnel

When laser overexposures occur, AFI 48–139 requires various offices/agencies to be immediately contacted to ensure all proper actions are taken to protect the individuals involved and prevent further exposures.

Office of Primary Responsibility (OPR)	Contact Responsibility
ILSO	Immediately coordinates medical care and investigation with FSO. Notifies installation safety office, public health, judge advocate and applicable major command (MAJCOM), Air Force Reserve (AFR) or Air National Guard (ANG) medical staff. Contacts workplace supervisor immediately to ensure actions are taken to prevent further injury. Contacts the Tri-Service Laser Injury Hotline (1-800-473-3549). Consults with USAFSAM/OE or the ESOH Service Center.
Workplace supervisor	Immediately notifies unit commander, ILSO, ULSO, BE, installation safety office and public health of accident/incident. Must make contact no later than eight hours of the accident/incident.
Individual	Reports to workplace supervisor and ULSO any suspected laser or optical radiation overexposure.

Investigation

After all appropriate personnel have been notified of the incident, the ILSO and/or installation safety must begin a detailed investigation to determine event characteristics, the root cause, contributing factors, and corrective measures. Installation safety investigates accidents/incidents related to exposures causing operational impacts, causing damage to systems and/or sensors, or ancillary safety hazards associated with a laser or any optical radiation system according to AFI 91–204, *Safety Investigation and Hazard Reporting*. Other MTF personnel should also be included in the investigation, as needed. For example, public health is required to initiate and complete an occupational illness investigation in the Air Force Safety Automated System (AFSAS) and is also required to ensure medical follow-up examinations are conducted for those identified as having been potentially overexposed. In addition, security forces personnel should be included in the investigation if there are indications of malicious intent.

For personnel overexposures, the following information shall be determined and documented, as defined in AFI 48–139, Attachment 4:

- Name, rank, and social security number of individual(s) suspected to have been overexposed.
- Laser, broadband, or other optical radiation source nomenclature, characteristics and operating parameters at the time of the incident/accident (wavelength, peak and average power, pulse width and frequency, beam diameter and divergence, etc.) including those parameters that may be classified, if pertinent to the investigation.
- Date, time, place, unit, duration of the exposure, and the individual’s position relative to the laser/optical source.
- A thorough description of the events leading up to the accident/incident. A signed narrative statement shall be obtained from all individuals involved and/or having knowledge of the accident/incident.
- Personal protective equipment and/or clothing in use at the time of the incident/accident. The wavelength and OD for which protection is afforded/associated with any laser eye protection (LEP) in use.
- Facility configuration at time of the event.
- Name, rank, address, and telephone number of the attending physician. If the attending physician is not an AF physician, give name, rank, title, address, and telephone number of the consulting AF physician.
- Assessment of root cause, confounding or contributing factors, and corrective measures to prevent re-occurrence.

It is essential that the event be reconstructed by BE if possible and measurements and (or) calculations made to ascertain as nearly as possible the exposure level to the individuals. If the equipment and expertise do not exist locally to fully investigate and reconstruct the incident, support should be requested through the ESOH Hotline and the MAJCOM BE.

Reporting and documentation

The primary purpose of an accident report is to document the information obtained during the investigation; therefore, proper documentation and reporting is essential. There are two specific reporting requirements outlined in AFI 48–139, initial and final reporting.

Initial reporting

Per AFI 48–139, Attachment 4, the ILSO is required to complete the Department of Defense (DOD) laser accident/incident reporting form and submit it to the Tri-Service Laser Injury Hotline within three duty days following a laser accident or incident. The DOD reporting form may be found on the ESOH Service Center Website (https://hpws.afrl.af.mil/dhp/OE/ESOHSC/) or by contacting the Tri-Service Laser Injury Hotline, 1-800-473-3549.

Final reporting

Upon completing the investigation and within 30 duty days, the ILSO shall forward a detailed report to installation public health, BE, safety, legal office, MAJCOM BE, and AFMSA/SG3PB with a courtesy copy to ESOH Service Center for entry into the laser and optical radiation exposure investigation repository. The report should be executed in AFSAS and shall include a minimum of the following:

- A summary of the estimated exposure.
- A timetable of medical evaluations.
- A discussion of further medical follow-up recommendations.
- Copies of the reconstruction report.
- Copies of all narrative statements, medical evaluations, and/or human factors evaluation.
- Investigation findings.
- Recommendations to prevent recurrence.

Defense Occupational and Environmental Health Readiness System documentation

Documentation of the exposure data can be difficult to manage without a comprehensive system. According to AFI 48–145, *Occupational and Environmental Health Program*, the DOEHRS is the DOD-approved occupational and environmental health (OEH) management information system (MIS) used to manage and archive OEH exposure data, and DOEHRS is used to manage longitudinal exposure recordkeeping and reporting. The DOEHRS provides BE the capability to document incident exposures via the Incident Reporting module. Although not specified in AFI 48–139, documentation of exposures resulting from an accident/incident should be included as part of the individuals' longitudinal exposure record, and therefore documented in DOEHRS.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

614. Laser fundamentals

1. Where in the EM spectrum is laser radiation created?

2. Explain what collimated means.

3. What is the significance of using 0.25 second as exposure duration?

615. Biological effects of lasers

1. Which type of potential eye damage would you anticipate from a laser with a wavelength of 425 nm?

2. Which type of eye injury can result from rapid heating of the tissue with short pulse durations?

616. Identifying/analyzing laser sources and hazards

1. What sources of information are available if you have unidentified laser systems on your installation?

2. Why is it important to find out if a laser has more than one operating "mode" or "wavelength"?

617. Maximum permissible exposure limits and nominal hazard zones for lasers

1. What is the definition of MPE?

2. What is the nominal hazard zone?

618. Laser controls

1. What is optical density?

2. What software program can be used to calculate the OD and which OD fields are listed?

3. What standard/document includes recommended controls for each of the laser classifications?

619. Investigate potential laser overexposures or accidents

1. What is the AFI that provides guidance on laser overexposures?

2. As part of a laser overexposure accident/incident investigation, when should the workplace supervisor notify the unit commander, safety officer, ULSO and ILSO?

Answers to Self-Test Questions

614

1. Radiation is created in the IR, visible, and UV portions of the EM spectrum.
2. The laser beam is emitted as a tight column of light that does not spread out, or “diverge” much as it travels away from its source.
3. It is the accepted amount of time for any person to avert the eyes from a laser beam (aversion response).

615

1. Retinal burns or thermal burns (lesions) in the eye.
2. Thermo mechanical.

616

1. DOEHRS and the USAFSAM ESOH Service Center Laser Homepage.
2. There can be different MPEs for different combinations of wavelength and exposure duration.

617

1. The level of laser radiation to which a person may be exposed without hazardous effects or adverse biological changes in the eye or skin.
2. The NHZ is the space within which the level of the direct, reflected, or scattered radiation during normal operation exceeds the applicable MPE.

618

1. The ability to reduce laser energy as it passes through protective eyewear material.
2. LHAZ, Max additional OD and additional OD required (at range).
3. ANSI Z136.1, Table 10.

619

1. AFI 48–139, *Laser and Optical Radiation Protection Program.*
2. The workplace supervisor shall notify the unit commander, safety officer, ULSO and ILSO within 8 hours of the accident/incident.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to AFCDA.

28. (614) Which laser property means the laser beam is emitted as a tight column of light that does not spread out, or “diverge” much as it travels away from its source?
    a. Coherence.
    b. Collimated.
    c. Amplification.
    d. Continuous wave.

29. (614) The three components required for a laser to operate are laser medium, optical cavity, and
    a. light source.
    b. focusing lens.
    c. pumping system.
    d. targeting mirror.

30. (614) Which laser classification is incapable of causing injury during normal operation?
    a. Class 4.
    b. Class 3.
    c. Class 2.
    d. Class 1.

31. (615) What is the *most* common cause of laser-induced tissue injury?
    a. Thermal.
    b. Indirect.
    c. Blindness.
    d. Photochemical.

32. (615) Which hazard is a non-beam hazard associated with the use of lasers?
    a. Photokeratitis.
    b. Compressed gases.
    c. Pigment darkening.
    d. Thermo mechanical.

33. (616) Which laser does *not* require a laser hazard evaluation?
    a. Class 1.
    b. Class 3B.
    c. Class 4.
    d. Military specific.

34. (616) Which is *not* one of the three primary operational aspects that influence a laser hazard evaluation?
    a. Personnel or populations exposed to laser radiation.
    b. Laser system’s capability to cause injury.
    c. Environment in which the laser is used.
    d. Nominal Hazard Zone.

35. (617) What is often limited indoors by the walls and ceilings of the room where the laser is used?
    a. Beam pathway.
    b. Exposure pathway.
    c. Nominal hazard zone (NHZ).
    d. Nominal ocular hazard distance (NOHD).

36. (617) The nominal hazard zone (NHZ) is the space within which the level of the direct, reflected, or scattered radiation during normal operation exceeds
    a. causes reversible eye damage.
    b. causes irreversible eye damage.
    c. the appropriate hazard distance.
    d. the applicable maximum permissible exposure limit.

37. (617) For outdoor operations, the nominal hazard zone (NHZ) may be limited somewhat by
    a. terrain.
    b. elevation.
    c. temperature.
    d. barometric pressure.

38. (617) The distance from a laser to a point where the energy of the beam falls below the ocular maximum permissible exposure level is
    a. Nominal hazard zone (NHZ).
    b. Upper tier environment (UTE).
    c. Estimated hazard distance (EHD).
    d. Nominal ocular hazard distance (NOHD).

39. (618) Which skin cover fabric provides the *best* protection against lasers?
    a. Loose.
    b. Light colored.
    c. Tightly woven.
    d. Darkly colored.

40. (618) Which method is an example of an administrative control for the use of lasers?
    a. Key controls.
    b. Safety training.
    c. Viewing windows.
    d. Controlling the use of optics.

41. (619) Which person delegates authority to the Installation Laser Safety Officer (ILSO) to suspend operations involving the operation of laser or other optical radiation sources that pose a significant health risk to personnel?
    a. Installation commander.
    b. Medical group commander.
    c. Major command (MAJCOM) commander.
    d. MAJCOM bioenvironmental engineer.

42. (619) Within how many duty days of completion of a laser incident investigation does the installation laser safety officer (ILSO) forward a detailed report to installation public health, bioenvironmental engineering (BE), safety, legal office (JA), major command (MAJCOM) BE, and Air Force Medical Support Agency.
   a. 5.
   b. 20.
   c. 30.
   d. 90.

Please read the unit menu for unit 4 and continue ➔

Student Notes

Unit 4. Optical Radiation

ULTRAVIOLET (UV), VISIBLE, AND IR RADIATION are called optical radiation because they behave according to the laws and principles of geometric optics. UV and IR radiation are found both naturally and in a wide range of occupational settings. Optical radiation is not as hazardous as ionizing radiation (e.g., gamma & x-rays). However, if not properly controlled both UV and IR have the ability to pose considerable health risk to exposed workers.

620. Ultraviolet radiation sources, hazards, and controls

UV radiation lies between the visible and x-ray portions of the EM spectrum (100-400 nms). It is considered nonionizing radiation. Within this region, UV is categorized into three wavelength bands: UV-A, UV-B, and UV-C (fig. 4–1). This is simply a convenient way of classifying UV rays based on the amount of energy they contain and their hazardous effects on exposed biological matter. Since UV-C consists of the shortest wavelengths, it is the most energetic and most harmful while UV-A is the least energetic and least harmful of the three.

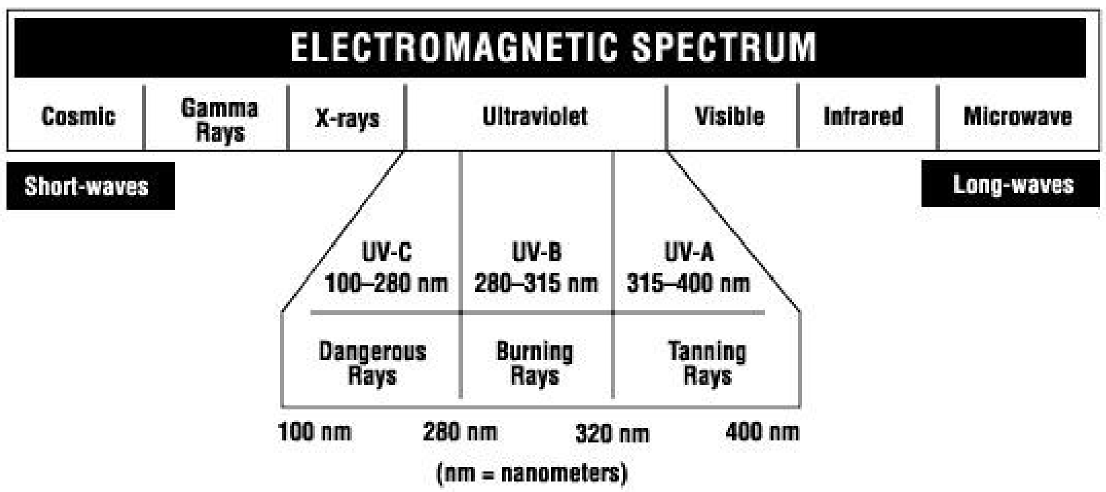

Figure 4–1. UV spectral region of the EM spectrum.

Ultraviolet radiation sources

The sun is the primary natural source of UV radiation. Artificial sources include black lights, lamps used for treating skin disorders, UV spectroscopy, curing processes, germicidal applications, photomicrolithography, chemical manufacturing, photoluminescence, mercury vapor lamps, tanning beds, and fluorescent and incandescent sources. The primary occupational sources of UV radiation in the AF include welding and metal cutting that occurs in maintenance and transportation shops, some nondestructive inspection processes, and exposure to the sun (fig. 4–2).

Figure 4–2. Welding is a common UV radiation source.

Ultraviolet radiation hazards

Unique hazards apply to different UV sources depending on the wavelength range of the emitted radiation.

UV-A rays are the most commonly encountered type of UV rays; UV-A exposure has an initial pigment-darkening (tanning) effect, followed by erythema (i.e., reddening/sunburn) if the exposure is excessive. Humans need UV-A to synthesize vitamin D; however, overexposure to UV-A has been linked to skin toughening, immune system suppression, and cataract formation. Most often, UV-A light is referred to as black light.

UV-B rays are slightly stronger than UV-A rays. The UV-B rays are typically the most destructive form of UV radiation because they have enough energy to cause photochemical damage to cellular deoxyribonucleic acid (DNA) but not enough to be completely absorbed by the atmosphere (like UV-C rays). Just like UV-A, UV-B is also needed by humans to synthesize vitamin D; however, harmful overexposure effects can include erythema, cataracts, and skin cancer. These rays are sensitive to the angle of the sun and are greatest when the sun is overhead; from about 10 a.m. to 2 p.m. Individuals working outdoors during these times are at the greatest risk for UV-B overexposure.

UV-C rays are the strongest of the UV rays. UV-C rays are almost never observed in nature because they are absorbed completely in the earth's atmosphere. Germicidal lamps emit UV-C radiation in order to kill bacteria. In humans, UV-C rays are absorbed in the outer layer of the epidermis (i.e., skin). Overexposure to UV-C can cause corneal burns, commonly termed welder's flash. Injuries related to UV-C typically clear up in a day or two; however, they can be extremely painful.

Ultraviolet rays have more energy than visible light, but not as much as x-rays. The target organs for UV radiation are the skin, eyes, and immune system. Skin effects of importance from occupational exposures to UV radiation include erythema, photosensitivity, premature aging, and cancer. Ocular effects include photokeratoconjuctivitis (an inflammatory issue), cataracts, and other retinal effects.

Effect of UV radiation on the skin

The most common adverse response of the skin to UV radiation is erythema. The UV radiation penetrates the living cells of the dermis and causes damage which the body repairs. Blood supply to the skin is increased as part of the repair process, this causes the reddening. Repeated exposure to UV rays, particularly UV-B rays, causes the skin to thicken and harden leaving the skin with a leathery appearance.

Most skin cancers are a direct result of overexposure to UV rays. Three types of skin cancers are of concern: squamous cell carcinomas and basal cell carcinomas, referred to jointly as nonmelanoma skin cancer, and cutaneous malignant melanoma. These cancers tend to be found on sun-exposed parts of the body, and their occurrence is often related to lifetime sun exposure. Melanoma is the most serious form of skin cancer and also one of the fastest growing types of cancer in the United States.

Ultraviolet radiation exposure also depresses both the systemic and local immunological response. Effects that have been observed include altered function of epidermal Langerhans cells, reduced T cells (possibly a transient effect), inhibition of natural killer cell activity, and changes in cytokine regulation.

Some beneficial or therapeutic effects are produced by UV exposure, including vitamin D_3 synthesis and therapy for skin conditions including vitiligo, psoriasis, mycosis fungoides, acne, eczema, and pityriasis rosea. In some treatments, photosensitizing agents are used to enhance the effect of UV radiation.

A study that examined nonsolar sources of UV found no increased risk of basal or squamous cell carcinomas associated with welding, mercury vapor lamps, or black lights sources.

Effects of UV radiation on the eyes

The target organs for UV radiation are the skin, eyes, and immune system. The eyes are particularly sensitive to UV radiation from 210 nm-320 nm (UV-C and UV-B). Even a short exposure can result in photokeratoconjunctivitis—a temporary but painful condition caused by inflammation of the cornea of the eye in which the eye waters and vision is blurred. Conjunctivitis is the inflammation of the conjunctiva—the membrane that covers the inside of the eyelids and the sclera (the white of the eye). The membrane becomes swollen and produces a watery discharge. It causes discomfort rather than pain and does not typically affect vision.

Absorption of UV radiation from 320 nm – 400 nm (UV-A) in the lens may be a factor in producing cataracts. Cataracts are a form of eye damage in which the eye lens loses transparency and clouds vision. When untreated, cataracts can lead to blindness. Other examples of eye disorders resulting from UV exposure include flash burn and welder's flash, depending on the source of the UV light causing the injury. Symptoms include pain, discomfort similar to the feeling of sand in the eye, and an aversion to bright light. These problems can be lessened with proper UV radiation eye protection.

Certain chemicals and medications act as photosensitizing agents and enhance the effect of UV radiation from sunlight or other sources. Some common agents include thiazides, diuretics, tetracycline, doxycycline, sulfa antibiotics, and nonsteroidal anti-inflammatory drugs, such as ibuprofen (e.g., Advil, Motrin). It is important to note these photosensitizing effects only occur in people exposed to both UV radiation and a photosensitizing agent.

The table provides a summary of the biological effects associated with UV radiation exposure.

Spectral Division	Spectral Range (nm)	Eye	Skin
UV-C	100-280	Photokeratitis	Erythema
UV-B	280-315	Cataract Photokeratitis	Erythema Accelerated aging Cancer (e.g., melanoma)
UV-A	315-400	Lens yellowing	Pigment darkening Photosensitivity Burns

Overexposure to UV radiation can lead to serious health issues. It is critical to protect personnel, which can be accomplished through a variety of ways.

UV radiation controls

Controls for sun exposure include avoiding working in the sun, wearing protective clothing and hats, and applying sunscreens. Protective clothing can include long pants, hats, and long-sleeved shirts. Sun-resistant clothing and fabrics are effective in blocking UV radiation.

In relation to non-solar sources of UV radiation, well designed administrative and engineering controls, and in some instances, personal protective equipment, can keep the risks to a minimum. There are several measures that can be put in place to control risks in the workplace.

Administrative controls

For outdoor workers this includes, whenever possible, rescheduling outdoor work details to be performed outside the peak UV radiation period (10 a.m. – 2 p.m.), moving the jobs indoors or to shady areas, and/or rotating workers between indoor and outdoor tasks to lessen each worker's total UV exposure. In the context of non-solar sources of UV radiation, administrative controls include warning signs, keeping staff at a safe distance from the source, and limiting the time during which UV radiation sources are switched on.

Because sunblock and sunscreen effectiveness in preventing melanoma has not been established, other protective measures such as hats and protective clothing, and avoiding sun exposure during peak hours should be used.

Engineering controls

For outdoor workers this includes shade cover or canopies. In the context of non-solar sources of UV radiation, suitable engineering control measures include opaque barriers, UV radiation blocking filters, and door interlocking access to shut off sources when the protective enclosure is open. Most common materials transmit little UV, although this is a function of wavelength, material thickness, and angle of incidence. All UV types (A, -B, and -C) have been found in fluorescent lamps used in open fixtures, but UV-B and UV-C can be blocked when an acrylic diffuser is used with the fixture. Commercially available welding curtains may be made of materials that are either opaque or transparent to visible wavelengths. Opaque materials include canvas duck, asbestos substitutes, and polymer laminates. Transparent welding curtains may allow visual contact with welders, reduce arc glare, and increase general illumination levels.

Personal protective equipment

Sun-exposed outdoor workers should be provided protective clothing that is loose fitting, made of closely woven fabric and provides protection to the neck and preferably the lower arms and legs. Hats can be worn to shade the face, neck, and ears. Sunglasses should also be worn.

Sunscreens provide another means of protection against UV radiation. Sunscreens are rated according to the sun protection factor (SPF), an index of protection against skin erythema. SPF ranges from 1 – 100; the higher the SPF, the more protection it offers from UV-B radiation. Limiting exposure time and properly applying sunscreen provide the most effective methods of controlling overexposure to natural UV radiation.

Sunblock

Sunblock creates a physical barrier, which reduces exposure by reflecting and scattering the incident radiation. Zinc oxide and titanium dioxide are very effective sunblocks, reflecting up to 99 percent of the radiation both in the UV and visible regions, possibly into the IR region also. Unlike sunscreen, metal oxide sunblocks do not degrade from exposure to sunlight.

Sunscreens

Sunsceens absorb UV over a limited wavelength range in the UV-B and UV-A regions. The agents in sunscreens are regulated by the United States Food and Drug Administration; some sunscreen agents include para-aminobenzoic acid (PABA) and its esters, benzophenones, salicylates, cinnamates, and anthranilates. All provide protection in the UV-B range; only the benzophenones and anthranilates provide limited protection in the UV-A region. The PABA preparations can discolor clothing and can cause contact-type, eczematous dermatitis.

In the context of non-solar sources of UV radiation, arc welders in particular need to be provided with purpose-specific eye protective equipment. For welding, cutting, or soldering operations, the guide for the selection of proper filter lens shade numbers is given in ANSI Z87.1, *Occupational and Educational Personal Eye and Face Protection Devices*, or AFMAN 91-203, *Air Force Occupational Safety, Fire, and Health Standards*. OD is the quantity used to specify the attenuation of protective eyewear.

Recommended threshold limit values of ultraviolent radiation

The TLV for an occupational exposure to UV radiation to the skin or the eyes represent conditions under which it is believed that nearly all healthy workers may be repeatedly exposed without acute adverse health effects such as erythema and photokeratitis. These values for exposure of the eye or the skin apply to UV radiation from arcs (arc welding operation), gas and vapor discharges, fluorescent and incandescent sources, and solar radiation. The recommended TLVs for occupational exposure to UV radiation can be found in the most current copy of the *ACGIH TLV Booklet*. These values are specified in joules per square meter (J/m^2) and millijoules per square centimeter (mJ/cm^2) – where 1 mJ/cm^2 = 10 J/m^2.

UV radiation has numerous useful applications, but increased awareness and control of UV hazards are needed to prevent accidental exposure.

621. Infrared radiation sources, hazards, and controls

The IR region lies between the visible and microwave portions of the electromagnetic spectrum (770 nm-1 mm). “Near-IR” is nearest in wavelength to visible light and “far-IR” is farther from visible light (i.e., closer to the microwave region of the spectrum).

Far-IR waves are thermal. In other words, this type of IR radiation is found in the form of radiant heat. The heat felt from sunlight or a fire is far-IR radiation. Often, IR lights are used to heat food-special lamps that emit thermal IR waves are often used in fast food restaurants for this purpose.

Near-IR (shorter waves) is not hot at all. These shorter waves are the ones used by television and other remote controls.

Since the primary source of IR radiation is heat or thermal radiation, essentially all objects radiate IR. Even objects that are thought of as being very cold, such as an ice cube, emit IR. When an object is not quite hot enough to radiate visible light, it will emit most of its energy in IR. For example, hot charcoal may not give off light, but it will emit IR radiation felt as heat. The warmer the object, the more IR radiation the object will emit.

IR sources

All objects with temperatures above absolute zero (–273°C or –459.67°F) emit IR radiation. The sun is the major source, along with various lamps, projection systems, welding arcs, and lasers. Also, a number of lasers and optical wireless communications systems use IR-emitting diodes. The primary occupational sources of IR radiation found in the Air Force include heated metals, welding arcs, lasers, and paint drying infrared heaters.

IR hazards

The damage to skin from IR exposure results from a temperature increase in the absorbing tissue. The increase depends on the wavelength, the parameters involved in heat conduction and dissipation, the intensity of the exposure, and the duration. The most prominent effects of near-IR include acute skin burn, increased vasodilation of the capillary beds, and an increased pigmentation than can persist for long periods of time. It is evident that the rate at which the temperature of the skin is permitted to increase is of prime importance.

High levels of far-IR, also referred to as radiant heat, are encountered in activities such as glassblowing, welding, and molten metal processes. Because IR is detectable as heat which can lead to heat loading in the body, IR exposures can be a significant contributor to thermal stress.

IR also produces thermal effects to the eye. Initially, heating occurs in the anterior portions of the eye, especially the cornea and iris, which can lead to cataract formation. The cornea, however, is highly transparent to IR-A. Moderate IR doses can result in pupil constriction (miosis), hyperemia, and aqueous flares. More severe exposures may lead to muscle paralysis, congestion with hemorrhage, thrombosis and stromal inflammation. Within a few days, necrosis of the iris may cause bleached atrophic areas to form. The table that follows provides an overview of IR radiation and the associated biological effects.

Spectral Division	Spectral Range (nm)	Eye	Skin
IR-A	770–1400	Retinal injuries Thermal cataract	Burns
IR-B	1400–3000	Aqueous flare Corneal burn Thermal cataract	Burns
IR-C	>3000	Corneal burn	Burns

Infrared hazard controls

As with other electromagnetic radiation, IR hazard controls rely on time to reduce total dose, distance (inverse square law applies), and shielding in the form of physical barriers, protective clothing, and eye protection. The selection of barriers should be based on the wavelength. The IR standards can also be found in the near-IR tables of the *ACGIH TLV Booklet*. The TLVs for occupational exposure of the eyes to near-IR radiation apply to exposures in any 8-hour workday.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

620. Ultraviolet radiation sources, hazards, and controls

1. What wavelength range is associated with the UV radiation region of the EM spectrum?

2. What are the three wavelength bands common to UV radiation?

3. Why are UV-B rays considered the most destructive form of UV radiation?

4. What is the repeated effect of UV-B rays to the skin?

5. What are the organs most affected (target organs) for UV radiation?

6. What is the spectral range within which the eyes are *most* sensitive to UV radiation?

7. What are *common* ways to *limit* sun exposure?

8. When considering non-solar sources of UV radiation, what measures can be used to keep risks to a *minimum*?

9. Opaque barriers and blocking filters are examples of which type of ultraviolet radiation hazard control method?

10. Describe the type of clothing outdoor workers should wear to protect against UV radiation.

11. What is the *most* effective way to control overexposure to natural UV radiation?

12. What do the TLVs associated with an occupational exposure to UV radiation represent?

621. Infrared radiation sources, hazards, and controls

1. What type of IR radiation waves are considered thermal?

2. What is the primary source of IR radiation?

3. What are the main occupational sources of IR radiation found within the AF?

4. List the most prominent effects associated with overexposure to near-IR.

5. What are the biological effects to the eyes from exposure to UV radiation in the spectral range of 1400-3000 nm?

6. List three methods of IR radiation hazard controls.

7. What IR radiation hazard control method results in a reduction in total dose?

8. Physical barriers and protective clothing are examples of what IR radiation hazard control method?

9. What determines the type of barrier selected as a control for IR radiation?

10. What is the timeframe upon which TLVs for an occupational exposure to the eye(s) from near-IR radiation are based?

Answers to Self-Test Questions

620

1. 100 – 400 nm.
2. UV-A, UV-B, and UV-C.
3. They have enough energy to cause photochemical damage to cellular DNA but not enough energy to be completely absorbed by the atmosphere – like UV-C rays.
4. Skin, eyes, and the immune system.
5. The skin thickens and hardens resulting in a leathery appearance.
6. 210 – 320 nm.
7. Avoid working in the sun; wear protective clothing; and apply sunscreen.
8. Limit exposure time and always ensure sunscreen is properly applied.
9. Engineering controls, administrative controls, and personal protective equipment.
10. Engineering.
11. Loose fitting, made of closely woven fabric and provides protection to the neck and preferably the lower arms and legs.
12. The conditions under which it is believed that nearly all healthy workers may be repeatedly exposed without acute adverse health effects.

621

1. Far-IR.
2. Heat or thermal radiation.
3. Heated metals, welding arcs, lasers, and paint drying infrared heaters.
4. Acute skin burn; increased vasodilation of the capillary beds; and an increased pigmentation that can persist for long periods of time.
5. Aqueous flare, corneal burn, and thermal cataract.
6. Time, distance, and shielding.
7. Time.
8. Shielding.
9. Wavelength.
10. 8-hour workday.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to AFCDA.

43. (620) Within what spectral region of the electromagnetic spectrum does ultraviolet radiation fall?
   a. 100–400 nanometers.
   b. 400–700 nanometers.
   c. 700–1400 nanometers.
   d. 1400–3000 nanometers.

44. (620) Which condition can be attributed to repeated exposure to ultraviolet radiation by the skin?
   a. Conjunctivitis.
   b. Photokeratitis.
   c. Flash burn.
   d. Erythema.

45. (620) Which action provides the *most* effective method of controlling overexposure to natural ultraviolet radiation?
   a. Using blocking filters.
   b. Limiting exposure time.
   c. Wearing opaque barriers.
   d. Installing interlocking doors.

46. (621) Near-infrared radiation is closest in wavelength to what region of the electromagnetic spectrum?
   a. Radar.
   b. X-ray.
   c. Microwave.
   d. Visible light.

47. (621) In which item would near-infrared radiation be used?
   a. Black light.
   b. Germicidal lamp.
   c. Television remote.
   d. Mercury vapor lamp.

48. (621) Which biological effects can be associated with an overexposure to infrared radiation?
   a. Phytosensitivity.
   b. Lens yellowing.
   c. Corneal burn.
   d. Flash burn.

49. (621) Which control principle, when applied to infrared radiation, results in a reduction in total dose?
   a. Personal protective equipment.
   b. Shielding.
   c. Distance.
   d. Time.

50. (621) When determining infrared radiation hazard controls, selection of a barrier is dependent upon
    a. wavelength.
    b. thermal load.
    c. total exposure time.
    d. distance from the source.

51. (621) Upon what timeframe are the threshold limit values (TLV) for an occupational exposure of the eyes to near-infrared radiation based?
    a. 7-day workweek.
    b. 5-day workweek.
    c. 8-hour workday.
    d. 10-hour workday.

Student Notes

Glossary of Abbreviations and Acronyms

μsec	microsecond
A/m	amperes per meter
AF	Air Force
AFI	Air Force instruction
AFMAN	Air Force manual
AFOSH	Air Force Office of Safety and Health
AFR	Air Force Reserve
AFSAS	Air Force Safety Automated System
AGCIH	American Conference of Governmental Industrial Hygienists
AM	amplitude modulation
ANG	Air National Guard
ANSI	American National Standards Institute
AOC	area of concern
BE	bioenvironmental engineering
BEE	bioenvironmental engineer
cm	centimeter
cps	cycles per second
CW	continuous wave
dB	decibels
dBm	decibel output relative to one mW
dBW	decibel output relative to one watt
DF	duty factor
D_{MPE}	hazard distance
DNA	deoxyribonucleic acid
DOD	Department of Defense
DODI	Department of Defense instruction
DOEHRS	Defense Occupational and Environmental Health Readiness System
E	electric; energy
ECM	electronic countermeasure
EHF	extremely high frequency
EM	electromagnetic
EMF	electromagnetic frequency

ESOH	Environment, Safety, and Occupational Health
eV	electron volt
FM	frequency modulation
FSO	flight surgeon's office
G_{abs}	absolute gain
G_{abs}	absolute gain
GHz	gigahertz
H	magnetic
h	Planck's Constant Energy Level
HF	high frequency
Hz	hertz
IEEE	Institute of Electrical and Electronic Engineers
ILS	instrument landing system
ILSO	installation laser safety officer
IR	infrared
IRSO	installation radiation safety officer
J/m^2	Joules per square meter
kHz	kilohertz
km	kilometer
LEP	laser eye protection
LF	low frequency
LHAZ	Laser Hazard Analysis Software
LSO	laser safety officer
M^2	square meters
MAJCOM	major command
MF	middle frequency
MHz	megahertz
MIS	management information system
mJ/cm^2	millijoules per square centimeter
MPE	maximum permissible exposure
MTF	military treatment facility
mW	milliwatt
MW	megawatt
mW/cm^2	milliwatt per square centimeter

NCO	noncommissioned officer
NHZ	nominal hazard zone
nm	nanometer
NOHD	nominal ocular hazard distance
OD	optical density
OEH	occupational and environmental health
OEHSA	occupational and environmental health site assessment
OPR	office of primary responsibility
PABA	para-aminobenzoic acid
PAR	precision approach radar
P_{ave}	average power
P_p	peak power
PRF	pulse repetition frequency
PRSO	permit radiation safety officer
PW	pulse width
RAM	radioactive material
RFR	radio frequency radiation
RICS	Radioisotope Committee Secretariat
RRF	rotational reduction factor
SAR	specific absorption rate
SEG	Similar Exposure Group
SHF	super-high frequency
SOP	standard operating procedure
SPF	sun protection factor
STD	standard
TACAN	tactical air navigation
TIC	toxic industrial chemical
TIM	toxic industrial material
TLV	Threshold Level Value
TWA	time weighted average
UHF	ultrahigh frequency
ULSO	unit laser safety officer
URSO	unit radiation safety officer
USAF	United States Air Force

USAFSAM	United States Air Force School of Aerospace Medicine
UV	ultraviolet
v	frequency
V/m	volts per meter
VHF	very high frequency
VLF	very low frequency
VOR	very high frequency omnidirectional range
W	watts
W/kg	watts per kilogram
W/m²	watts per square meter

Student Notes

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