

Radiation Safety Manual*

Part III

Requirements for Sources that Produce Non-Ionizing Electromagnetic Radiation



University of California, Riverside

Environmental Health & Safety

* Available from EH&S Radiation Safety and on the UCR EH&S web site www.ehs.ucr.edu/.

Part II, "Requirements for Lasers".

Part II, "Requirements for Lasers".

Contact Information

EH&S Web Site	www.ehs.ucr.edu
Radiation Safety Information & Services	
EH&S Radiation Safety	Extension 2-5529
Radioactive Waste Pickup	
Integrated Waste Management	Extension 2-5518
Emergencies (8:00 a.m. - 5:00 p.m.)	Extension 2-5529
Emergencies (after-hours and on weekends)	
Ask For EH&S Radiation Safety	Dial 9-1-1 (campus phone)

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1.00 Overview

Non-ionizing electromagnetic radiation includes a broad range of frequencies from near zero to those of ultraviolet radiation. The health effects of this type of radiation are well known for some frequencies, unknown for others, and controversial for still others. Regulations related to the use of non-ionizing radiation are not detailed probably because most are directed to specific radiation uses and because of the uncertainty of the related health effects. Though there are few regulations directed to these sources of radiation, there are recommendations/consensus standards that have been adopted by groups such as the "The American National Standards

Institute" (ANSI), and "The Institute of Electronic and Electronics Engineers" (IEEE) (these two documents are basically the same) that have tended to fill the regulatory void and are thus considered acceptable practices to be followed.

The following requirements supplement the general information contained in the UCR Radiation Safety Manual and are based on the applicable regulations, recommendations, and consensus standards related to non-ionizing radiation and apply to those sources [e.g. radio-frequency (RF), microwave, ultraviolet, and infrared radiation] used at UCR.

Most of the regulations that govern the safe use of sources of non-ionizing electromagnetic radiation are contained in Title 29, CFR, Section 1910.97. Since these regulations are general in nature, limited in scope, and apply mainly to health concerns in industrial applications, modifications are necessary to deal with the educational/research issues (e.g. effects of EM fields on nearby equipment) in a university setting.

Based on the requirements in the regulations and the recommendations by ANSI and IEEE, as well as the potential health effects and the potential to effect nearby equipment (e.g. video displays, credit cards, attraction of ferromagnetic objects), the following requirements have been developed for sources that produce non-ionizing electromagnetic radiation used at UCR.

2.00 General Requirements

2.01 Acquisition, Modification, Transfer, and Disposal of Sources That Produce Non-Ionizing Radiation

Notify EH&S Radiation Safety prior to acquisition, modification, transfer and/or disposal of a high intensity source that produce non-ionizing radiation.

- a) Submit an "Application for Use of Sources of Non-Ionizing Radiation" to the EH&S Radiation Safety that includes the following information:
 - Description of the machine (type of machine, manufacturer, model, year of manufacture, frequency).
 - Operating procedure.
 - Sample "Use Log Book", if required.
 - Expected radiation field intensity in area around the source, if required.
 - A description of safety interlocks/devices, if required.

2.02 Facility/Equipment Review/Inspections

Plans for facilities that include high intensity sources of non-ionizing radiation must be reviewed before initial operation, after modifications that might affect field intensities in areas around the source, and periodically thereafter. Inspections are to assure that the facility is safe and in compliance with appropriate Federal, State, and Local regulations.

a) Initial Review

Prior to initial operation of a new source of high intensity non-ionizing radiation, it shall be inspected by EH&S Radiation Safety. The inspection is intended to determine if the facility/radiation producing machine is safe for the intended use and that it is in compliance with appropriate Federal, State, and Local regulations.

b) Modifications

Prior to initial operation of a source of high intensity non-ionizing radiation that has had significant modifications that could impact the safety of the source, it shall be inspected by EH&S Radiation Safety.

c) Periodic Inspections

EH&S Radiation Safety will periodically inspect sources of non-ionizing radiation to assure that they are in safe operating condition and in compliance with appropriate Federal, State, and Local regulations.

2.03 Notification

Notify EH&S Radiation Safety prior to initial operation and after modification of any significant source(s) of non-ionizing radiation.

2.04 Annual Update

Each year, any individual responsible for a source of non-ionizing radiation shall submit an "Annual Update Report" to EH&S Radiation Safety. The report will include the following information:

a) Facility changes anticipated

b) User changes

c) Comments related to operational problems, hazards, etc.

2.05 Maximum Allowed Exposures (field strengths, power densities, and currents)

Sources of non-ionizing radiation shall be used in such a way that exposures (field strengths, power densities, and currents) in the work and adjacent areas are as low as reasonably achievable but:

a) Shall not exceed the exposure limits specified in 29, CFR, 1910.97 (see Table I)

b) Should not exceed the exposure limits recommended by ANSI/IEEE (see Table II)

- c) Should not affect the work or equipment located in the work or adjacent areas.

Contact EH&S Radiation Safety for more detail.

Table I: EXPOSURE LIMITS FROM 29 CFR, 1910.97

These limits apply to work (controlled) areas for exposure times greater than 0.1 hour when averaged over any 0.1 hour period:

Frequency Range (MHz)	Power Density (mW/cm ²)	Energy Density (mW-hr/cm ²)
10 to 100,000	10	1

The limits shown in Tables IIA – IID are those recommended by The American National Standards Institute (ANSI) and The Institute of Electrical and Electronics Engineers (IEEE) for controlled and uncontrolled areas.

Table IIA: Maximum Permissible Exposure to Electromagnetic Fields^b for Controlled Environments

Frequency Range (MHz)	E (V/m)	H (A/m)	Power Density (S) E-Field, H-Field (mW/cm ²)	Averaging Time $ E ^2$, $ H ^2$, or S (minutes)
0.003 to 0.1	614	163	(100,1,000,000) ^c	6
0.1 to 3	614	16.3/f	(100,10,000/f ²) ^c	6
3 to 30	1842/f ^a	16.3/f	(900/f ² ,10,000/f ²) ^c	6
30 to 100	61.4	16.3/f	(1.0,10,000/f ²) ^c	6
100 to 300	61.4	0.163	1.0	6
300 to 3000			f/300	6
3,000 to 15,000			10	6
15,000 to 300,000			10	616,000/f ^{1.2}

- a) f = frequency in MHz
- b) The exposure values in terms of electric and magnetic field strengths are the values obtained by spatially averaging values over an area equivalent to the vertical cross-section of the human body (projected area).
- c) These plane-wave equivalent power density values, although not appropriate for near-field conditions, are commonly used as a convenient comparison

with MPEs at higher frequencies and are displayed on some instruments in use.

Table IIB: Maximum Permissible Exposure to Induced and Contact Radio Frequency Currents^b for Controlled Environments

Frequency Range (MHz)	Maximum Current (mA)		Contact
	Through both feet	Through each foot	
0.0003 to 0.1	2000f ^a	1000f ^a	1000f ^a
0.1 to 100	200	100	100

- a) f = frequency in MHz
- b) It should be noted that the current limits given above may not adequately protect against startle reactions caused by transient discharges when contacting an energized object.

Table IIC: Maximum Permissible Exposure to Electromagnetic Fields^b for Uncontrolled Environments

Frequency Range (MHz)	E (V/m)	H (A/m)	Power Density (S) E-Field, H-Field (mW/cm ²)	Averaging Time E ² , S H ² (minutes)	
0.003 to 0.1	614	163	(100,1,000,000) ^c	6	6
0.1 to 1.34	614	16.3/f	(100,1,000,000) ^c	6	6
1.34 to 3	823.8/f ^a	16.3/f	(180/f ² ,10,000/f ²) ^c	f ² /0.3	6
3 to 30	823.8/f	16.3/f	(180/f ² ,10,000/f ²) ^c	30	6
30 to 100	27.5	158.3/f ^{1.668}	(0.2,940,000/f ^{6.336}) ^c	30	0.0636f ^{1.337}
100 to 300	27.5	0.0729	0.2	30	30
300 to 3000			f/1,500	30	
3,000 to 15,000			f/1,500	90,000/f	
15,000 to 300,000			10	616,000/f ^{1.2}	

- a) f = frequency in MHz
- b) The exposure values in terms of electric and magnetic field strengths are the values obtained by spatially averaging values over an area equivalent to the vertical cross-section of the human body (projected area).
- c) These plane-wave equivalent power density values, although not appropriate for near-field conditions, are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

Table IID: Maximum Permissible Exposure to Induced and Contact Radio Frequency Current's^b for Uncontrolled Environments

Frequency Range (MHz)	Maximum Current (mA)		Contact
	Through both feet	Through each foot	
0.0003 to 0.1	900f ^a	450f ^a	450f ^a
0.1 to 100	90	45	45

- a) f = frequency in MHz
- b) It should be noted that the current limits given above may not adequately protect against startle reactions caused by transient discharges when contacting an energized object.

2.06 Field Strength Monitoring

To assure that the field strengths around sources of non-ionizing radiation are as low as reasonably achievable and do not exceed acceptable limits (see above), area surveys shall be performed prior to initial operation, following modifications, and periodically thereafter.

2.07 Shielding, Interlocks, Safety/Warning Devices and Measures

Certain safety devices/measures may be required to reduce field strengths in occupied areas and to reduce effects on nearby equipment. Required safety measures include:

- a) Warning lights
- b) Field strength meters
- c) Interlocks
- d) Shielding
- e) Controlled access
- f) Lockout-Blockout (formerly Lockout-Tagout)

All required safety device/measure shall be maintained, and shall not be replaced or modified without specific approval by EH&S Radiation Safety. No safety device is absolutely fail-safe or foolproof so should act only as a backup, not as a replacement for proper procedures.

Required safety devices/measures must never be purposely defeated. If the design of a safety device makes a desired/necessary operation inconvenient or impossible, an alternate device shall be designed that provides the same degree of protection. Proposals to modify safety devices shall be approved by EH&S Radiation Safety prior to operation of the source of non-ionizing radiation. When

safety devices/measures are modified it may be necessary to modify existing operating procedures and to retrain operators. If a required safety device/measure fails, the source must not be operated until it is repaired and subsequently checked by EH&S Radiation Safety. EH&S Radiation Safety must be notified immediately when a safety device/measure failure has or may have resulted in an unexpected personnel exposure to an EM field.

2.08 Operating Procedures

Operating procedures approved by EH&S Radiation Safety must be available, in the work area, to all users of machines that produce non-ionizing radiation.

2.09 Posted Instructions and Signs

Posting and labeling of radiation producing machines and/or use areas shall be in accordance with the requirements in 17 CCR 30278. Requirements include:

- a) Operating/safety instructions
- b) Warning signs as appropriate

2.10 Training

All users of machines that produce non-ionizing radiation must have documented training that is adequate for the work being performed.

Training shall include the following topics:

- a) A description of what non-ionizing radiation is
- b) Effects of non-ionizing radiation
- c) Exposure limits
- d) Potential exposures for the work to be done
- e) Exposure reduction methods
- f) A description of pertinent Federal, State, and local regulations
- g) An introduction of the radiation safety program at UCR (see UCR Radiation Safety Manual).
- h) Required notices, signs, warnings, and labels
- i) Operating procedures for the equipment being used
- j) Techniques to monitor for non-ionizing radiation, if required
- k) Medical surveillance requirements, if any

Remember: Compliant training for users of sources that produce non-ionizing radiation should be approved by EH&S Radiation Safety.

2.11 Machine Location

As a general safety precaution and/or to allow security during unattended operation it may be desirable to dedicate an entire room to a machine that produces non-ionizing radiation. When this is not possible/desirable, the machine should be placed in an interlocked enclosure or in an area that is away from high occupancy and/or traffic flow and to which access is limited by barriers and identified by appropriate signs/labels. Exposures to non-ionizing radiation shall be maintained as low as reasonably achievable but in no case shall exceed regulatory limits or any limits specified in the UCR Radiation Safety Manual. Contact EH&S Radiation Safety before installing or moving a machine/source that produces significant exposures to non-ionizing radiation.

2.12 Electrical Safety

The high voltages and electrical currents that can be associated with machines that produce non-ionizing radiation can present a serious hazard to personnel if proper safety precautions are not followed. The following basic principles apply:

- a) Electrical circuit breakers will be clearly marked and each worker shall be instructed as to the location and procedure for turning off specific breakers in an emergency situation.
- b) During some routine maintenance operations it may be necessary to utilize a Lockout-Blockout (formerly Lockout-Tagout) procedure, contact EH&S for details.
- c) All modifications to power lines and/or power supplies shall be performed using an approved Lockout-Blockout procedure (contact EH&S for details). For those times when live high current or high voltage power supplies are inspected, two members shall be present in the laboratory. Both members should be trained in emergency procedures involving electrical hazards.

2.13 Hazardous Material/Biohazard Safety

Hazardous and biohazardous materials are sometimes used in conjunction with machines that produce non-ionizing radiation. Special safety precautions may be necessary to protect people from the risks associated with these special hazards.

Examples:

- a) Hazardous and/or biohazardous materials may be used during machine operation. These materials shall be handled and disposed according to practices that are acceptable at UCR (see UCR Chemical Hygiene Plan, or UCR Biosafety Manual for details). Contact EH&S if there are questions.
- b) Hazardous fumes and/or vapors (e.g., chemical, biological) may be generated during operation that require management by exhaust fans, collection devices, personnel protective equipment, etc. Contact EH&S if there are questions.

3.00 Summary of Requirements for Specific Machine Categories

The following summaries may not be complete for all circumstances so modifications may be necessary. Call EH&S Radiation Safety if there are questions.

3.01 Microwave Sources

Microwaves are a portion of the electromagnetic spectrum in the radio frequency region that can cause heating of the eyes and/or other body organs. Standards in most of this region are related to communication, industrial, and military applications and are not primarily related to human health concerns. In the 1500-3000 MHz region of the spectrum, however, occupational, and public health standards exist for industrial, research and consumer microwave applications such as ovens, transmitters, etc. Specifically, at 2450 MHz, the commonest frequency of microwave ovens the exposure limit is 5 mW/cm². For questions regarding specific applications see Section 2.05 of this manual and/or call EH&S Radiation Safety.

3.02 Magnetic Fields

Strong magnetic fields can attract ferromagnetic objects (e.g., iron) so violently that they can cause physical injury to users and/or equipment; however, according to the best current information there are no human health effects that result from exposures to magnetic fields. Very intense static fields have not produced any significant effects in a variety of investigations. Nevertheless, some effects have been found in other experimental conditions and as a consequence precautionary health standards have been developed. For example, the maximum permissible exposure to a magnetic field (H-field) for a 600 MHz source in an uncontrolled environment is 0.40 mW/cm² that corresponds to an H-field strength of 0.1 A/m. Intense magnetic fields are commonly encountered in high-energy physics, nuclear magnetic resonance (imaging and spectroscopy) and other areas of university research and development. For questions regarding specific applications see Section 2.05 of this manual and/or call EH&S Radiation Safety.

3.03 Ultraviolet Sources

Broadband ultraviolet (UV) sources are known to produce biological effects and since these effects are cumulative and chronic it is important to maintain a minimum exposure. Exposure guides vary considerably depending on wavelength, exposure duration, environment, application, and other factors. For example, the exposure limit for the UVA region (315 nm - 400 nm) is 1.0 mW/cm² total per work day while exposure limits in the actinic UV region (180 nm - 314 nm) vary with the biological action for the various effects.

In the actinic UV region, photokeratitis (eye damage) and skin erythema (sun burn) are the principle acute health hazards associated with exposure while skin cancer is the most likely chronic effect. For this reason, certain medical germicidal lamps ($\lambda = 254$ nm) have limits as low as 0.1 μ W/cm² for a 24-hour period and 0.5 μ W/cm² for a seven-hour period while at other wavelengths in this region the exposure limit is 10 or 100 times higher. For questions regarding specific applications see Section 2.05 of this manual and/or call EH&S Radiation Safety.

In general, good practice dictates skin and eye protection when working where UV radiation is present. Laboratory coat, UV protective goggles, and gloves are usually adequate.

3.04 Infrared Sources

Infrared sources create an additional thermal load that the body must dissipate. If this radiant energy is focused or is of a nature that a single organ must bear the load (e.g., the eye), a serious health hazard may exist. The principal adverse effect attributed to infrared radiation is infrared cataracts ("glass blowers' cataracts"). Hazardous levels for the eye and skin are comparable beyond 1.4 μm , since the injury mechanism is largely thermal. Beyond 1.9 μm the cornea is considered the sole absorber in this region when infrared energy is delivered to the ocular media. As with other regions of the electromagnetic spectrum, exposure limits vary with wavelength, duration, and condition of exposure. As an example, 10 mW/cm^2 is the occupational ocular exposure limit for IR-A (780 nm - 1400 nm). For questions regarding specific applications see Section 2.05 of this manual and/or call EH&S Radiation Safety.

Good practice dictates the use of skin and eye protection when working with high intensities of infrared radiation. In general, Laboratory coat, protective goggles, and gloves are adequate, however, if there are questions contact EH&S Radiation Safety.

Appendices

I. Summary of Good Practices for the Use of Sources that Produce Non-Ionizing Electromagnetic Radiation

General Description of Issues

Non-ionizing radiation is usually not a serious hazard, but there are very real safety and health concerns associated with it. The major verified hazards from non-ionizing radiation are hazards to pacemakers and other medical electronic implants at zero hertz, mechanical hazards to metallic implants and flying projectiles caused by magnetic fields at zero hertz, interference with the functioning of pacemakers at lower frequencies, electric shock and burns from contact currents at all frequencies up to about 100 MHz, and cataracts/skin burns at higher frequencies in the MHz to GHz range. Magnetic field shielding is difficult because it involves diverting flux lines around the protected space rather than simply blocking them. When appropriate, an experienced firm should be hired to design electric or magnetic field shielding. The requirements and/or guidance items that follow are accompanied by references to relevant regulatory and guidance sources. In addition, there may be comments that should give practical insights into the implications of the requirements and/or methods for implementing them.

Static (Zero Hertz) Magnetic Fields

1. The anticipated field in the building shall be mathematically modeled before installation begins to identify where pacemaker and metallic implant/projectile hazards will exist, where field strengths exceed 5 and 30 gauss, respectively. Places where excessive exposures, >2000 gauss, could occur shall also be identified.

International Commission on Non-Ionizing Radiation Protection. "Guidelines on Limits of Exposure to Static Magnetic Fields," *Health Phys.* 66, 100–106 (1994).

Threshold Limit Values for Physical Agents.

This area has generally been ignored by EH&S professionals so little lore and few "good practices" exist, even in the face of experience and the existence of proven hazards. Math modeling is mandated because it is now practical and will show where access controls and sign postings are needed.

2. Provisions shall be made to keep people away from places where magnetic fields exceed 2000 gauss and offices shall be located where fields are <5 gauss to allow completely unrestricted access.

See the note for the preceding paragraph.

3. Provisions shall be made for limiting access and for posting warnings before people enter places where field strengths could exceed 5 gauss. Provisions shall be made for people to leave their wallets, magnetic media, keys, and other ferrous-alloy and magnetizable tools and articles for safekeeping before entering places where fields exceed 5 gauss.

International Commission on Non-Ionizing Radiation Protection. "Guidelines on Limits of Exposure to Static Magnetic Fields," *Health Phys.* 66, 100–106 (1994).

Threshold Limit Values for Physical Agents.

Engineered access controls, such as cypher-locked doors with hard-wired beacons, are preferred over impromptu measures such as stanchions and portable signs or beacons because even a staple left in a pocket can cause a painful injury and a wrench could kill or cause major equipment damage. This document is about the only time when anyone considered developing orthodox safety precautions for magnetic fields. Ten gauss has been associated with erasing credit cards and magnetic media while stronger fields make the other articles projectile hazards.

4. Provisions shall be made to direct the gas from a quenched superconducting magnet to a safe, unoccupied location to avoid exposing people to oxygen deficiencies. The issue of oxygen deficiency shall be addressed in designing cryogenic systems for superconducting magnets.

8CCR5144/29CFR 1910.134

8CCR5157/29CFR 1910.145

Power Frequency Fields

Provisions shall be made to keep people from places where field strengths could be hazardous to pacemaker users, ten gauss and 1 kV/m.

Physical Agent TLVs.

Overexposures are extremely unlikely because the exposure limits so high that few people, besides utility workers, encounter such fields. The carcinogenicity of power frequency fields is unproven so no guidance can be given for this issue at this time.

Radiofrequency and Microwave Energy (frequencies from 3 kHz to 300 GHz)

1. Provisions shall be made to protect people from exposures above the Maximum Permissible Exposure limits (MPEs). Engineering controls shall be used, whenever possible. Shielding shall be designed by or be reviewed by an Electronic Engineer experienced in radio frequency/microwave design.

IEEE C95.1-1991

Engineering controls, such as shielding, cypher-locked doors with hard-wired beacons, are preferred over impromptu measures such as stanchions and portable signs or beacons because time limit controls are framed in six minute intervals which makes limiting exposure duration impractical in most cases and because the efficacy of available PPE is still being determined and because the PPE will tend to be expensive. The paucity of EH&S consideration is again acknowledged.

2. Provisions shall be made for limiting access and for posting warnings before people enter places where field strengths could exceed MPEs.

IEEE C95.2-1982 or latest revision

See the note for the preceding paragraph.

3. Provisions shall be made to protect people from contact with radio frequency electrical

currents or sufficiently close proximity to allow exposures to exceed MPEs for rf electrical currents. These provisions shall be designed by or be reviewed by an Electronic Engineer experienced in radio frequency/microwave design.

IEEE C95.1-1991 for ambient field strengths.

International Commission on Non-Ionizing Radiation Protection, "Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (Up To 300 GHz)", Health Physics, 74: 494-522 (1998) for rf electric current flow limits.

The rf current flow MPEs from ICNIRP are more protective and should be applied. It is also noted that rf current flow can begin when two conductors are separated by up to about a foot because of electric field interactions ("capacitive coupling") between them so insulation alone may not work. Separation will be needed in such cases.

References

The following references may be useful. Contact EH&S Radiation Safety for more choices.

1. Title 8, California Code of Regulations (CCR), Section 30278
2. Title 29, Code of Federal Regulations (CFR), Part 1910.97
3. Safety Levels With Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz, ANSI, Report C95.1-1992
4. Safety Levels With Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz, IEEE, Report C95.1-1991
5. Radio Frequency Radiation Hazard Warning Symbol, ANSI C95.2-1982
6. American Conference of Governmental Industrial Hygienists (ACGIH), 1992, Threshold Limit Values for Chemical Substances and Physical Agents. ACGIH, Cincinnati, OH.

Glossary

A

Average (Temporal) Power (P_{avg}): The time-averaged rate of energy transfer.

$$P_{avg} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} P(t) dt$$

Averaging Time (T_{avg}): The appropriate time period over which exposure is averaged for purposes of determining compliance with an MPE. For exposure durations less than the averaging time, the maximum exposure, MPE', in any time interval equal to the averaging time is found from

$$MPE' = MPE \left(\frac{T_{avg}}{T_{exp}} \right)$$

where T_{exp} is the exposure duration in that interval expressed in the same units as T_{avg} . Restrictions on peak power density limit T_{exp} .

C

Continuous Exposure: Exposure for durations exceeding the corresponding averaging time. Exposure for less than the averaging time is called short-term exposure.

Controlled Environment: Controlled environments are locations where there is exposure that may be incurred by persons who are aware of the potential for exposure as a concomitant of employment, by other cognizant persons, or as the incidental result of transient passage through areas where analysis shows the exposure levels may be above those shown in Table 2 but do not exceed those in Table 1, and where the induced currents may exceed the values in Table 2, Part B, but do not exceed the values in Table 1, Part B (**Note:** The means for the identification of these areas is at the discretion of the operator of a source).

D

Duty Factor: The ratio of pulse duration to the pulse period of a periodic pulse train. A duty factor of 1.0 corresponds to continuous-wave (CW) operation.

E

Electric Field Strength (E): A field vector quantity that represents the force (F) on a positive test charge (q) at a point divided by the charge.

$$E = \frac{F}{q}$$

Electric field strength is expressed in units of volts per meter (V/m).

Energy Density (Electromagnetic Field): The electromagnetic energy contained in an infinitesimal volume divided by that volume.

Exposure: Exposure occurs whenever and wherever a person is subjected to electric, magnetic

or electromagnetic fields or to contact currents other than those originating from physiological processes in the body and other natural phenomena.

Exposure, Partial-Body: Partial-body exposure results when RF fields are substantially non-uniform over the body. Fields that are non-uniform over volumes comparable to the human body may occur due to highly directional sources, standing-waves, re-radiating sources or in the near field. **See: RF “hot spot”.**

F

Far Field Region: That region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna. In this region (also called the free space region), the field has a predominantly plane-wave character, i.e., locally uniform distributions of electric field strength and magnetic field strength in planes transverse to the direction of propagation.

H

Hertz (Hz): The unit for expressing frequency, f. One hertz equals one cycle per second.

M

Magnetic Field Strength (H): A field vector quantity that is equal to the magnetic flux density divided by the permeability of the medium. Magnetic field strength is expressed in units of amperes per meter (A/m).

Magnetic Flux Density (B). A field vector quantity that results in a force (F) that acts on a moving charge or charges. The vector product of the velocity (v) at which an infinitesimal unit test charge, q, is moving with B, is the force that acts on the test charge divided by q.

$$\frac{F}{q} = (v \times B)$$

Magnetic flux density is expressed in units of Tesla (T). One T is equal to 10^4 Gauss (G).

Maximum Permissible Exposure (MPE): The rms and peak electric and magnetic field strengths, their squares, or the plane-wave equivalent power densities associated with these fields and the induced and contact currents to which a person may be exposed without harmful effect and with an acceptable safety factor.

Mixed Frequency Fields: The superposition of two or more electromagnetic fields of differing frequency.

N

Near-Field Region: A region generally in proximity to an antenna or other radiating structure, in which the electric and magnetic fields do not have a substantially plane-wave character, but vary considerably from point to point. The near-field region is further subdivided into the reactive near-field region, which is closest to the radiating structure and that contains most or nearly all of the stored energy, and the radiating near-field region where the radiation field predominates over the reactive field, but lacks substantial plane-wave character and is complicated in structure. **Note:** For most antennas, the outer boundary of the reactive near field region is

commonly taken to exist at a distance of one-half wavelength from the antenna surface.

P

Penetration Depth: For a plane electromagnetic wave incident on the boundary of a medium, the distance from the boundary into the medium along the direction of propagation in the medium, at which the field strength of the wave have been reduced to $1/e$ (36.8%) of the boundary values.

Power Density, Average (Temporal): The instantaneous power density integrated over a source repetition period.

Power Density (S): Power per unit area normal to the direction of propagation, usually expressed in units of watts per square meter (W/m^2) or, for convenience, units such as milliwatts per square centimeter (mW/cm^2) or microwatts per square centimeter ($\mu W/cm^2$).

For plane waves, power density, electric field strength (E) and magnetic field strength (H) are related by the impedance of free space, i.e., 377 ohms. In particular,

$$S = \frac{E^2}{377} = 377H^2$$

where E and H are expressed in units of V/m and A/m respectively, and S in units of W/m^2 . Although many survey instruments indicate power density units, the actual quantities measured are E or E^2 or H or H^2 .

Power Density, Peak: The maximum instantaneous power density occurring when power is transmitted.

Power Density, Plane-Wave Equivalent: A commonly used term associated with any electromagnetic wave, equal in magnitude to the power density of a plane wave having the same electric (E) or magnetic (H) field strength.

Pulse Modulated Field: An electromagnetic field produced by the amplitude modulation of a continuous wave carrier by one or more pulses.

R

Radio Frequency (RF): Although the RF spectrum is formally defined in terms of frequency as extending from 0 to 3000 GHz for purposes of this standard, the frequency range of interest is 2 kHz to 300 GHz.

Re-Radiated Field: An electromagnetic field resulting from currents induced in a secondary, predominantly conducting, object by electromagnetic waves incident on that object from one or more primary radiating structures or antennas. Re-radiated fields are sometimes called "reflected" or more correctly "scattered fields." The scattering object is sometimes called a "re-radiator" or "secondary radiator". See scattered radiation.

RF "Hot Spot": A highly localized area of relatively more intense radio-frequency radiation that manifests itself in two principal ways:

- 1) The presence of intense electric or magnetic fields immediately adjacent to conductive objects that are immersed in lower intensity ambient fields (often referred to as re-radiation), and
- 2) Localized areas, not necessary immediately close to conductive objects, in which there exists a concentration of radio-frequency fields caused by reflections and/or narrow beams produced

by high-grain radiating antennas or other highly directional sources. In both cases, the fields are characterized by very rapid changes in field strength with distance. RF hot spots are normally associated with very non-uniform exposure of the body (partial body exposure). This is not to be confused with an actual thermal hot spot within the absorbing body.

Root-Mean-Square (rms) The effective value, or the value associated with joule heating, of a periodic electromagnetic wave. The rms value is obtained by taking the square root of the mean of the squared value of a function.

S

Sealed Source: Any radioactive material that is permanently encapsulated in such manner that the radioactive material will not be released under the most severe conditions likely to be encountered by the source.

Scattered Radiation: An electromagnetic field resulting from currents induced in a secondary, conducting or dielectric object by electromagnetic waves incident on that object from one or more primary sources.

Short-Term Exposure: Exposure for durations less than the corresponding averaging time.

Specific Absorption (SA): The Quotient of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume (dV) of a given density (P).

$$SA = \frac{dW}{dm} = \frac{dW}{\rho dV}$$

The specific absorption is expressed in units of joules per kilogram (J/kg).

Specific Absorption Rate (SAR): The time derivative of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of given density (P).

$$SAR = \frac{d}{dt} \left(\frac{dW}{dm} \right) = \frac{d}{dt} \left(\frac{dW}{\rho dV} \right)$$

SAR is expressed in units of watts per kilogram (W/kg).

U

Uncontrolled Environment: Uncontrolled environments are locations where there is the exposure of individuals who have no knowledge or control of their exposure. The exposures may occur in living quarters or workplaces where there are no expectations that the exposure levels may exceed those shown in Table 2 and where the induced currents do not exceed those in Table 2, Part B. Transitory exposures are treated in 4.1.1.

W

Wavelength (λ): The wavelength (λ) of an electromagnetic wave is related to the frequency (f) and velocity (v) by the expression $v = f \lambda$. In free space the velocity of an electromagnetic wave is equal to the speed of light, i.e., approximately 3×10^8 m/s.