

Chapter 50: [Non-ionizing Radiation](#)

Selected Radio Frequency Exposure Limits

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URL: <http://www-group.slac.stanford.edu/esh/eshmanual/references/nirReqExplimits.pdf>

1 Purpose

This document presents a subset of data most applicable to potential *radio frequency (RF)* hazards at SLAC, reproduced from the Institute of Electrical and Electronics Engineers (IEEE) Standard C95.1-2005, “IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz” ([IEEE Std C95.1-2005](#)) and the American Conference of Governmental Industrial Hygienists (ACGIH), Threshold Limit Values (TLVs) and Biological Exposure Indices (BEIs)-2005 ([ACGIH TLVs and BEIs-2005](#)). The data are to be used by equipment owners and the non-ionizing radiation program manager when preparing preliminary hazard analyses and *radio frequency safety programs (RFSPs)*.

2 Requirements

RF installations at SLAC must comply with the *maximum permissible exposure (MPE)* limits given in IEEE Std C95.1-2005. These MPEs are grouped in two categories: “upper tier” MPEs, which are the limits in effect for controlled environments, and “lower tier” MPEs, which are the limits for the general public in uncontrolled environments. The lower tier MPEs are *action levels*: potential exposures at or above these levels require preparation of an RFSP (see Section 2.4). Once the RFSP is approved, a controlled RF environment is established in which exposures must not exceed the upper-tier MPEs (see Section 2.3).

Note *The upper tier MPEs (Section 2.3) have been modified to align with the ACGIH TLVs and BEIs-2005.*

Equipment owners are encouraged to consult the standards to verify that the equipment in question satisfies these MPE limits. Contact the non-ionizing radiation program manager for any specific questions regarding the data presented here or in the standards.

2.1 Symbols, Units, and Acronyms

A	ampere
BR	basic restriction
E	electric field strength vector, measured in V/m
E	electric field strength amplitude, measured in V/m
<i>f</i>	frequency, measured in Hz

EM	electromagnetic
GHz	gigahertz
H	magnetic field strength vector, measured in A/m
H	magnetic field strength amplitude, measured in A/m
Hz	hertz, cycles per second
kg	kilogram
kHz	kilohertz
J	joule
m	meter
MHz	megahertz
MPE	maximum permissible exposure
NIR	non-ionizing radiation
RF	radio frequency
RFSP	RF safety program
RMS	root mean square
S	equivalent power density vector in mW/cm^2
SAR	specific absorption rate
T	tesla
V	volt
W	watt
WBA	whole body average

2.2 Definitions

Note The definitions below for far and near fields apply to simple sources of RF and microwave radiation (such as antennas or radar dishes) and are provided as a general guideline. These definitions may not be accurate for complex or irregularly shaped sources such as arbitrary radiation from broken or improperly connected waveguide flanges. Separate measurements of both the electric and magnetic fields should be made until it is certain that one is well outside

the near field before relying on a single probe. A single probe is used only when the electric and magnetic fields are proportional, that is, the ratio of the two remains constant through space.

Current, induced body. Currents induced in an individual during exposure to radio frequency electromagnetic fields

Density, plane wave power. Although most RF exposure standards are written in terms of **E** and **H** fields, it is sometimes convenient to express field strength in terms of the equivalent plane wave power density, **S**, in watts per square meter (W/m^2)

Density, power. Power per unit area normal to the direction of propagation, usually expressed in terms of watts per square meter (W/m^2) or milliwatts per square centimeter (mW/cm^2). (The conversion between the two units is $10 \text{ W}/\text{m}^2 = 1 \text{ mW}/\text{cm}^2$.)

Energy, electromagnetic (EM). The total energy stored in the electric and magnetic fields in a given volume. If this electromagnetic energy is absorbed by a body, the energy will raise the body temperature, whether or not the energy is confined in space or radiated. For radiated fields, electromagnetic energy consists of an electric field and a magnetic field oscillating in unison.

*Environment, controlled RF.*¹ An area where the occupancy and activity of those within is subject to control and accountability as established by an RF safety program for the purpose of protection from RF exposure hazards. (Note that industry standard terminology for this definition is just *controlled environment*, but SLAC uses *controlled RF environment* to distinguish from an environment which is controlled with respect to other hazards, such as ionizing radiation.)

Exposure, maximum permissible (MPE). An exposure limit or guideline for RF energy exposure published by a recognized consensus standards organization, such as the IEEE. See also *action level*.

Factor, duty. The fraction of time a transmitter or source is emitting radiofrequency or microwave energy, usually expressed as the ratio of the time on to the sum of the time on and off during the averaging time. For continuous emitters, the duty factor is equal to 1. The duty factor is multiplied by the field measurement to obtain a time-averaged exposure.

Field, pulse-modulated. An electromagnetic field produced by the amplitude modulation of a continuous-wave radio frequency or microwave carrier signal at a known repetition rate with a controlled duty factor

*Frequency, radio (RF).*² A frequency that is useful for radio transmission. For purposes of this program, the frequency range of interest is 3 kHz to 300 GHz.

*Level, action.*³ The values of the electric and magnetic field strength, the incident power density, contact and induced current, and contact voltages above which steps must be initiated to protect against exposures that exceed the upper tier; specifically, implementation of an RF safety program

Radiation, electromagnetic (EM). The transmission of energy through space in wave form, which can be characterized in terms of a wavelength and a frequency

1 Definition per IEEE Std C95.1-2005

2 Definition per IEEE Std C95.1-2005

3 Definition per IEEE Std C95.1-2005

*Radiation, non-ionizing (NIR).*⁴ Includes all radiations and fields of the electromagnetic spectrum that do not normally have sufficient energy to produce ionization in matter; characterized by energy per photon less than about 12 eV, wavelengths greater than 100 nm, and frequencies lower than 3×10^{15} Hz

*Restriction, basic (BR).*⁵ Exposure restriction based on established adverse health effects that incorporates appropriate safety factors and is expressed in terms of the in situ electric field (3 kHz to 5 MHz), specific absorption rate (100 kHz to 3 GHz), or incident power density (3 GHz to 300 GHz)

Strength, electric field. The electric field strength, **E**, is a vector quantity that represents the force, **F**, on a positive test charge, *q*, at a point divided by the charge ($\mathbf{E} = \mathbf{F}/q$). Electric field strength is expressed in terms of a voltage gradient with units of volts per meter (V/m).

Strength, magnetic field. The force with which a magnetic field acts on an element of current situated at a particular point. Magnetic fields can be referred to in terms of two vector quantities: magnetic flux density, **B**, or the magnetic field strength, **H**. The literature pertaining to extremely-low-frequency (ELF) radiation typically uses magnetic flux density, and the RF community uses magnetic field strength. The International System of Units (SI) unit for flux density is the tesla (T). Another commonly used unit for flux density is milligauss (mG), where $1 \mu\text{T} = 10 \text{ mG}$. In contrast, the RF community expresses field strength in terms of amperes per meter (A/m). Field strength and flux density in vacuum are related by the following equation: $1 \text{ A/m} = 12.57 \text{ mG}$.

*Time, averaging.*⁶ The appropriate time period over which exposure is averaged for purposes of determining compliance with a maximum permissible exposure (MPE) limit or reference level

4 Definition per “Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz), International Commission on Non-Ionizing Radiation Protection.” *Health Physics* 74 (4): 494-522; 1998

5 Definition per IEEE Std C95.1-2005

6 Definition per IEEE Std C95.1-2005

2.3 Maximum Permissible Exposures

Note The following tables and graphs are numbered the same as the originals in Section 4 of IEEE Std C95.1-2005. Values in Table 8 have been modified to align with the ACGIH TLVs and BEIs-2005.

Table 8 Maximum Permissible Exposures for Controlled RF Environments

Frequency range (MHz)	RMS electric field strength (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)
0.1–3.0*	614*	16.3/f _M	-	6
3.0–30*	1842/f _M	16.3/f _M	(9000/f _M ² , 100000/f _M ²) ^b	6
30–100	61.4	16.3/f _M	(10, 100000/f _M ²) ^b	6
100–300	61.4	0.163	10	6
300–3000	-	-	f _M /30	6
3000–15000*	-	-	100	6*
15000–300000*	-	-	100	616,000/f _M ^{1.2} *

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 the 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 the table. See Note a) in Notes to Table 8 and Table 9

^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.

* Value given in ACGIH TLVs and BEIs-2005.

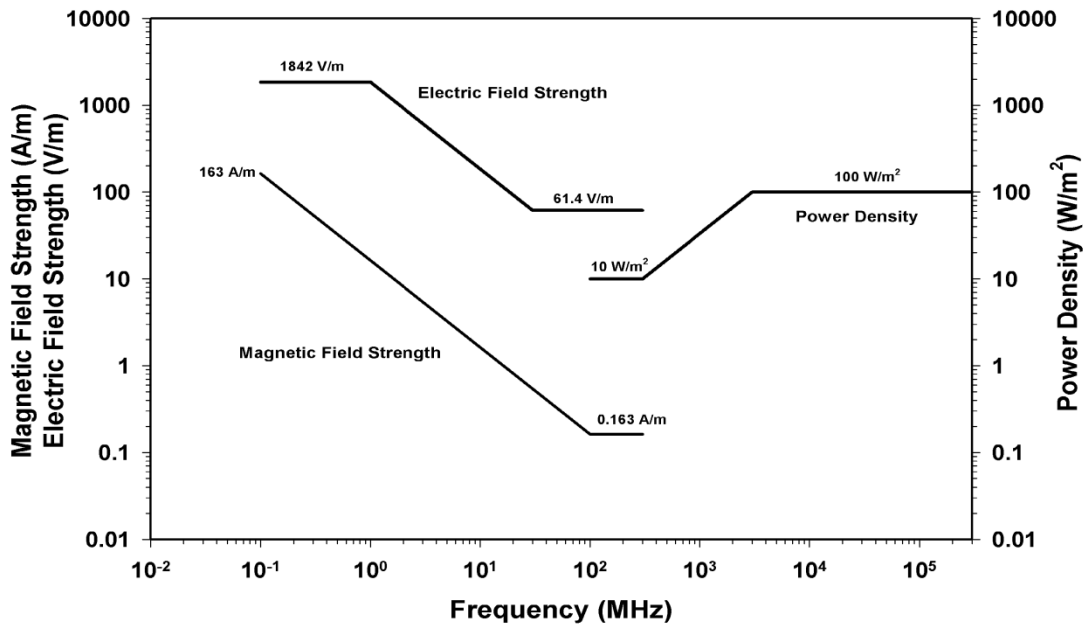


Figure 3 Graphic Representation of the MPEs in Table 8 (exposures in controlled environments) (note the electric field strength in this graph should be 614 V/m in the frequencies from 0.1 to 3.0 MHz)

2.4 Action Levels

The *action level* values in Table 9 indicate that an RF safety program (RFSP) plan must be initiated and submitted for review to the non-ionizing radiation program manager. Once the RFSP is approved, a *controlled RF environment* is established in which exposures must not exceed the limits shown in Table 8.

Table 9 Action Levels (Maximum Permissible Exposures for the General Public When No RFSP Exists)

Frequency range (MHz)	RMS electric field strength (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 ^b E ² , H ² , or S (min)	
0.1–1.34	614	16.3/f _M	(1000, 100000/f _M ²) ^c	6	6
1.34–3	823.8/f _M	16.3/f _M	(1800/f _M ² , 100000/f _M ²)	f _M ² /0.3	6
3–30	823.8/f _M	16.3/f _M	(1800/f _M ² , 100000/f _M ²)	30	6
30–100	27.5	158.3/f _M ^{1.668}	(2, 9400000/f _M ^{3.336})	30	0.0636f _M ^{1.337}
100–400	27.5	0.0729	2	30	30
400–2000	-	-	f _M /200	30	
2000–5000	-	-	10	30	
5000–30000	-	-	10	150/f _G	
30000–100000	-	-	10	25.24/f _G ^{0.476}	
100000–300000	-	-	(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 the 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 (see Notes to Tables, below), are compared with the MPEs in the table.
- ^b The left column is the averaging time for |E|², the right column is the averaging time for |H|². For frequencies greater than 400 MHz, the averaging time is for power density S.
- ^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.

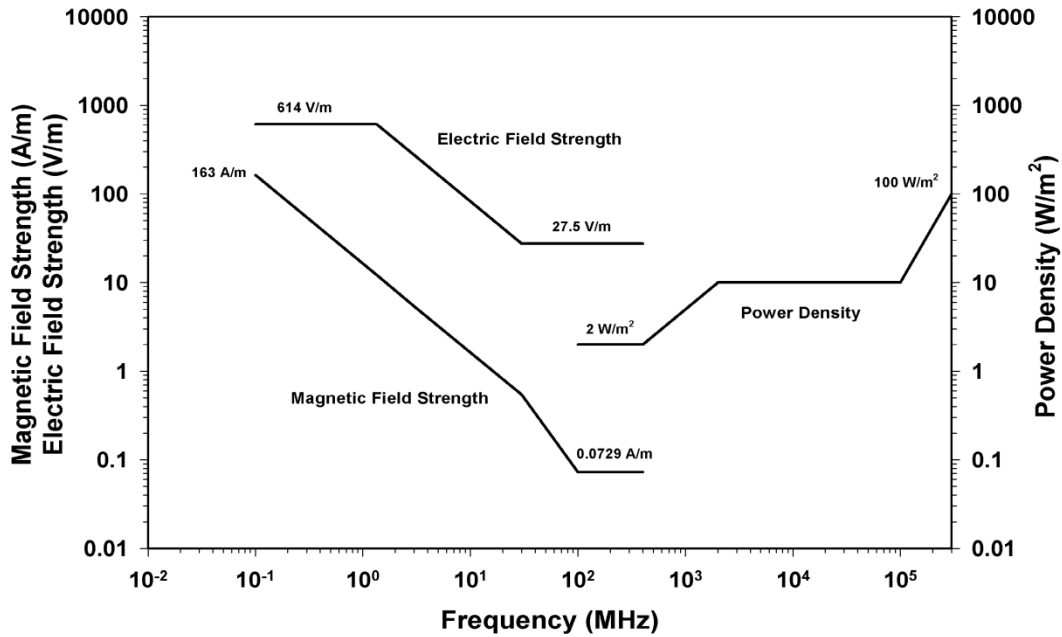


Figure 4 Graphic Representation of the MPEs in Table 9 (lower tier – action level)

2.5 Notes to Tables

- a) The MPEs refer to exposure values obtained by spatially averaging the electric and magnetic field strengths, the squares of the electric and magnetic field strengths, or the plane wave equivalent power densities along a line corresponding to the axis of the human body as follows:

Frequencies between 100 kHz and 3 GHz. The MPE for fields between 100 kHz and 3 GHz are derived on the basis of limiting the whole body averaged (WBA) SAR, which is proportional to the spatial average of the incident plane wave equivalent power density (or squares of electric and magnetic field strengths), averaged over the projected area of the body. Therefore, the MPE corresponds to the spatially averaged plane wave equivalent power density or the spatially averaged values of the squares of electric and magnetic field strengths. In practice, a measurement over the length of the body is sufficient for assessing exposures for comparison with the MPE.

Frequencies greater than 3 GHz. For frequencies greater than 3 GHz, the MPE is expressed in terms of the incident power density. However to provide a transition in the frequency range 3 GHz to 6 GHz, compliance with this standard may be demonstrated by evaluation of either incident power density or local SAR. From 3 GHz to 30 GHz, the power density is spatially averaged over any contiguous area corresponding to $100 \lambda^2$, where λ is the free space wavelength of the RF field in centimeters. For frequencies exceeding 30 GHz, the power density is spatially averaged over any contiguous area of 0.01 m^2 (100 cm^2).

- b) For near-field exposures at frequencies below 300 MHz, the applicable MPE is in terms of rms electric and magnetic field strength, as given in Table 8 and Table 9, columns 2 and 3. For convenience, the MPE may be expressed as equivalent plane-wave power density, given in Table

8 and Table 9, column 4. For frequencies below 30 MHz, both the rms electric and magnetic field strength must be determined; for frequencies between 30 and 300 MHz, either field component will be sufficient provided that the point in question is in the far-field of the source. For frequencies above 300 MHz, either field component may be used, when expressed as equivalent plane wave power density, for determining compliance with the MPEs in Table 8 and Table 9.

- c) For mixed or broadband fields at a number of frequencies for which there are different values of the MPE, the fraction of the MPE [in terms of $|\mathbf{E}|^2$, $|\mathbf{H}|^2$, or power density (\mathbf{S})] incurred within each frequency interval should be determined and the sum of all such fractions should not exceed unity. See Annex D of IEEE Std C95.1-2005 for an example of how this is accomplished. \
- d) In a similar manner, for mixed or broadband induced currents at a number of frequencies for which there are different values of the basic restriction, the fraction of the induced current limits (in terms of I^2) incurred within each frequency interval shall be determined, and the sum of all such fractions should not exceed unity.
- e) For exposures to pulsed RF fields, in the range of 100 kHz to 300 GHz, the peak (temporal) value of the MPE for the instantaneous peak \mathbf{E} field is 100 kV/m.
- f) For exposures to pulsed RF fields in the range of 100 kHz to 300 GHz, the peak pulse power densities are limited by the use of time averaging and the limit on peak \mathbf{E} field (100 kV/m), with one exception: the total incident energy density during any 100 ms period within the averaging time shall not exceed one-fifth of the total energy density permitted during the entire averaging time for a continuous field (1/5 of 144 J/kg), that is

$$\sum_{0\text{ s}}^{0.1\text{ s}} (S_{\text{pk}} \times \tau) \leq \frac{MPE_{\text{avg}} \times T_{\text{avg}}}{5} \leq 28.8 \text{ J/kg}$$

3 Forms

The following are forms required by these requirements:

- None

4 Recordkeeping

The following recordkeeping requirements apply for these requirements:

- None

5 References

[SLAC Environment, Safety, and Health Manual](#) (SLAC-I-720-0A29Z-001)

- [Chapter 50, “Non-ionizing Radiation”](#)
 - [Non-ionizing Radiation: Radio Frequency Source Review, Operation, and Maintenance Requirements](#) (SLAC-I-730-0A05S-013)
 - [Non-ionizing Radiation: Radio Frequency Source Review Procedure](#) (SLAC-I-730-0A05C-002)

Other SLAC Documents

- None

Other Documents

- Institute of Electrical and Electronics Engineers (IEEE) Standard C95.1-2005, “IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz” ([IEEE Std C95.1-2005](#))
- Institute of Electrical and Electronics Engineers (IEEE) Standard C95.1a-2010, “IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz. Amendment 1: Specifies Ceiling Limits for Induced and Contact Current, Clarifies Distinctions between Localized Exposure and Spatial Peak Power Density” ([IEEE Std C95.1a-2010](#))
- American Conference of Governmental Industrial Hygienists (ACGIH). Threshold Limit Values (TLVs) and Biological Exposure Indices (BEIs)-2005 ([ACGIH TLVs and BEIs-2005](#))
- “Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz), International Commission on Non-Ionizing Radiation Protection.” *Health Physics* 74 (4): 494-522; 1998