Notes:

1. These TLVs® are based on an assessment of available data from laboratory research and human exposure studies. Modifications of the TLVs® will be made if warranted by new information. At this time, there is insufficient information on human responses and possible health effects of magnetic fields in the frequency range of 1 Hz to 30 kHz to permit the establishment of a TLV® for time-weighted average exposures.
2. For workers wearing cardiac pacemakers, the TLV® may not protect against electromagnetic interference with pacemaker function. Some models of cardiac pacemakers have been shown to be susceptible to interference by power-frequency (50/60 Hz) magnetic flux densities as low as 0.1 mT. It is recommended that, lacking specific information on electromagnetic interference from the manufacturer, the exposure of persons wearing cardiac pacemakers or similar medical electronic devices be maintained at or below 0.1 mT at power frequencies.
3. Fields in excess of the TLV® are likely to be present only in close proximity to high powered electrical equipment; in most occupational environments sub-RF fields are likely to be far below the TLV®. There should consequently be little need for detailed field surveys in general occupational spaces, although such surveys may help to address workers' concerns. If field surveys are undertaken, however, they should use appropriate equipment that has been calibrated and suitable for the anticipated measurements. In particular, unless they are designed for such measurements, magnetic field meters can be significantly in error when used to measure nonsinusoidal waveforms or fields at frequencies other than 50/60 Hz.

TABLE 1. TLVs® for Sub-Radiofrequency(30 kHz and below) Magnetic Fields

Frequency Range	TLV®
1 to 300 Hz	Whole-body exposure: $\frac{60}{f^*}$ ceiling value in mT
1 to 300 Hz	Arms and legs: $\frac{300}{f^*}$ ceiling value in mT
1 to 300 Hz	Hands and feet: $\frac{600}{f^*}$ ceiling value in mT * where: f = frequency in Hz
300 Hz to 30 kHz	Whole-body and partial-body ceiling value: 0.2 mT
1 Hz to 2.5 kHz	Point contact current limit: 1.0 mA
2.5 to 30 kHz	Point contact current limit: 0.4 f mA where: f = frequency in kHz

SUB-RADIOFREQUENCY (30 kHz and below) AND STATIC ELECTRIC FIELDS

These TLVs® refer to the maximum workplace field strengths of sub-radiofrequency electric fields (30 kHz and below) and static electric fields that represent conditions under which it is believed that nearly all workers may be exposed repeatedly without special protection without adverse health effects. The electric field intensities in these TLVs® are root-mean-square (rms) values. The values should be used as guides in the control of exposure and should not be regarded as a fine line between safe and dangerous levels. The electric field strengths stated in these TLVs® refer to the field levels present in air, away from the surfaces of conductors (where spark discharges and contact currents may pose significant hazards).

Occupational exposures should not exceed a field strength of 25 kilovolts per meter (kV/m) at frequencies from 0 Hz to 220 Hz. For frequencies in the range of 220 Hz to 3 kilohertz (kHz), the ceiling value is given by:

$$E_{TLV} = 5.525 \times 10^6/f$$

where:

f = the frequency in Hz
E_{TLV} = the rms electric field strength in V/m

A rms value of 1842 V/m is the ceiling value for frequencies from 3 to 30 kHz. These ceiling values are intended for both partial-body and whole-body exposures.

Notes:

1. These TLVs® are based on limiting field-induced effects at the body surface and induced currents within the body to levels below those that are believed to be hazardous. These are direct effects.
2. Indirect effects associated with touching charged objects within the electric field can be the limiting phenomena that determine safe practice. A noticeable and potentially annoying spark discharge can be experienced beneath power lines when the ground level field strength is at or below 5 kV/m (EPRI, 2005). Mitigation of such effects requires compliance with safe work practices and electrical safety codes beyond the scope of this TLV®.
3. Certain biological effects have been reported in laboratory studies at electric field strengths below those permitted in the TLV®; however, there is no convincing evidence at the present time that occupational exposure to such field levels leads to adverse health effects.

Modifications of the TLVs® will be made if warranted by new information. At this time, there is insufficient information on human responses and possible health effects of electric fields in the frequency range of 0 to 30 kHz to permit the establishment of a TLV® for time-weighted average exposures.

Reference

Electrical Power Research Institute (EPRI): AC Transmission Line Reference Book — 200 kV and Above, 3rd Edition. EPRI, Palo Alto, CA (2005).

RADIOFREQUENCY/MICROWAVE RADIATION

These TLVs® refer to radiofrequency (RF) radiation in the frequency range of 30 kilohertz (kHz) to 300 gigahertz (GHz). This includes microwave radiation (300 MHz–300 GHz), which is a region of the RF spectrum. These TLVs® represent conditions under which it is believed nearly all workers may be repeatedly exposed without adverse health effects.

The TLVs® were designed to limit electrostimulation of nerve and muscle tissue at frequencies from 0.03 to 0.1 MHz, and tissue heating above 0.1 MHz. The TLVs® are given in terms of root-mean-square (rms) electric (E), and magnetic (H) field strengths, the equivalent plane-wave free-space power densities (S), and induced currents (**I**) in the body.

The TLVs® are summarized in Table 1 as a function of frequency, f, in megahertz (MHz). Table 2 summarizes the major dosimetric quantities in different frequency ranges specified in the TLV®, and major hazard mechanisms and typical exposure scenarios that would be of concern.

A. For exposures to electric and magnetic free fields, TLVs® in Table 1, Part A refer to exposure values obtained by spatially averaging over an area equivalent to the vertical cross-section of the human body (projected area). In the case of partial body exposure, the TLVs® can be relaxed. In nonuniform fields, spatial peak values of field strength may exceed the TLVs® if the spatially averaged specific absorption rate (SAR) value remains within the specified limits.

B. Access should be restricted to limit the rms RF body current and potential for RF electrostimulation ("shock," below 0.1 MHz) or perceptible heating (at or above 0.1 MHz) as follows (*see* Table 1, Part B):

1. For freestanding individuals (no contact with metallic objects), RF current induced in the human body, as measured through either foot, should not exceed the following values, where f is the frequency in MHz:

   I = 1000 f mA for (0.03 < f < 0.1 MHz) averaged over 0.2 s; where mA = milliampere

   I = 100 mA for (0.1 < f < 100 MHz) averaged over 6 min

2. For conditions of possible contact with metallic bodies, the maximum RF current that can be passed into the body as measured with a contact current meter should not exceed the following values:

   I = 1000 f mA for (0.03 < f < 0.1 MHz) (where f is the frequency in MHz) averaged over 0.2 s

   I = 100 mA for (0.1 < f < 100 MHz) averaged over 6 min

TABLE 1. Radiofrequency and Microwave TLVs®

Part A—Electromagnetic Fields[A] (f = frequency in MHz)

Frequency	Power Density, S (W/m^2)	Electric Field Strength, E (V/m)	Magnetic Field Strength, H (A/m)	Averaging Time E^2, H^2, or S (min)
30 kHz–100 kHz		1842	163	6
100 kHz–1 MHz		1842	16.3/f	6
1 MHz–30 MHz		1842/f	16.3/f	6
30 MHz–100 MHz		61.4	16.3/f	6
100 MHz–300 MHz	10	61.4	0.163	6
300 MHz–3 GHz	f/30			6
3 GHz–30 GHz	100			$34000/f^{1.079}$
30 GHz–300 GHz	100			$68/f^{0.476}$

[A]The exposure values in terms of electric and magnetic field strengths are obtained by spatially averaging over an area equivalent to the vertical cross-section of the human body (projected area). At frequencies between 100 MHz and 300 MHz, the TLV® is defined in the near field of the source in terms of electric and magnetic field, and in the far field in terms of the power density of the wave. At frequencies above 30 GHz, the power density TLV® is the limit of exposure averaged over any contiguous 0.01 m^2 of body surface. However, above 30 GHz the maximum power density is 1000 W/m^2 in any one square centimeter.

Part B—Maximum Induced and Contact Radiofrequency Currents (mA)[B]

Frequency	Through Both Feet	Through Either Foot	Grasping[B1]	Averaging Time
30 kHz–100 kHz	2000 f	1000 f	1000 f	0.2 s[C]
100 kHz–100 MHz	200	100	100	6 min[D]

[B] It should be noted that the current limits given above may not adequately protect against startle reactions and burns caused by transient discharges when contacting an energized object.

The ceiling value for induced and contact currents is 500 mA for no more than 15 s per 6 min period.

[B1] Maximum touch current is limited to 50% of the maximum grasping current.

[C] **I** is averaged over a 0.2 s period.

[D] **I** is averaged over a 6-minute period (e.g., for either foot or hand contact, i.e., $\mathbf{I}\ t < 60{,}000$ mA^2-min). In this table, f is the frequency in Hz.

3. For touch contact with conductive objects, the maximum RF current should not exceed more than one-half of the maximum RF current for grasping contact. The means of compliance with these current limits can be determined by the user of the TLVs® as appropriate. The use of protective gloves, the avoidance of touch contact with conductive objects, the prohibition of metallic objects, or training of personnel may be sufficient to ensure compliance with these TLVs®. Evaluation of the magnitude of the induced currents will normally require a direct measurement. However, induced and contact current measurements are not required if the spatially averaged electric field strength does not exceed the TLV® given in Table 1, Part A at frequencies between 0.1 and 100 MHz, as shown graphically in Figure 2.

C. For source frequencies greater than 100 MHz, Table 1, Part A provides an equivalent plane-wave power density, S (in W/m^2), which can be calculated from field strength measurement data as follows:

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

where: E^2 is in volts squared (V^2) per meter squared (m^2); and

$$S = 377\ H^2$$

where: H^2 is in amperes squared (A^2) per meter squared (m^2).

D. For exposures to pulsed fields of pulse duration less than 100 milliseconds (ms) at frequencies in the range 0.1 MHz to 300 GHz, the total incident energy density during any 100 ms period within the averaging time (see Table 1, Part A) shall not exceed 20% of the total specific energy absorption (SA) permitted during the entire averaging time for a continuous field, i.e., $0.2 \times 144 = 28.8$ J/kg. For pulse durations greater than 100 ms, normal time-averaging calculations apply.

The TLV® values in Table 1 should be used as guides in the evaluation and control of exposure to radiofrequency and microwave radiation and should not be regarded as fine lines between safe and dangerous levels. The values of E, H and S given in Table 1, Part A are shown graphically as a function of frequency in Figure 1. Figure 2 depicts the maximum permissible current values given in Table 1, Part B through one foot or touch current as a function of the maximum permissible electric field strength TLV® over the frequency range 0.1 to 100 MHz.

Notes:

1. It is believed that workers may be exposed repeatedly to fields up to these TLVs® without adverse health effects. Nevertheless, personnel should not needlessly be exposed to higher levels of RF radiation, approaching the TLVs®, when simple measures can prevent it.
2. For mixed or broadband fields at a number of frequencies for which there are different values of the TLV®, the fraction of the TLV® (in terms of E^2,

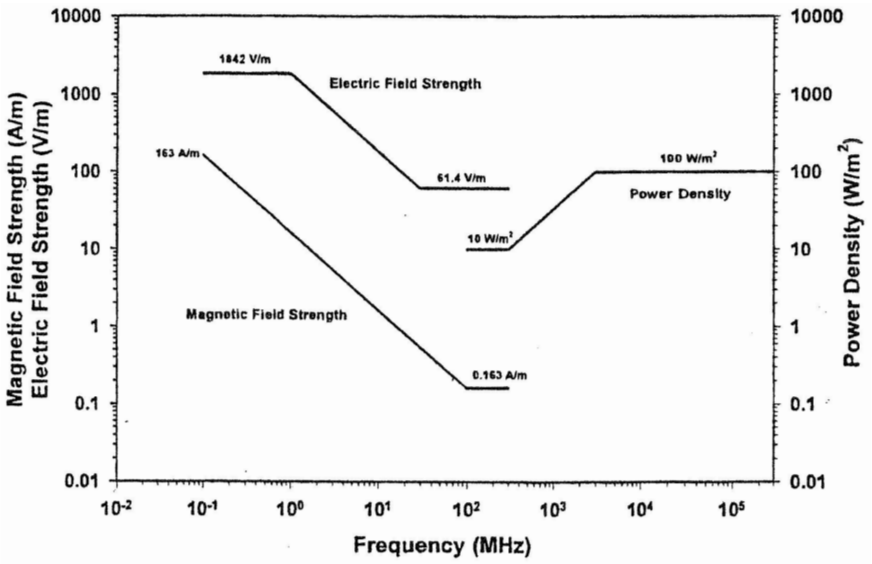

FIGURE 1. Threshold Limit Values (TLVs®) for Radiofrequency/Microwave Radiation in the workplace (for whole-body specific absorption rate [SAR] < 0.4 W/kg). (From IEEE Std. C95.1 – 2005a. Copyright © IEEE. All Rights Reserved).

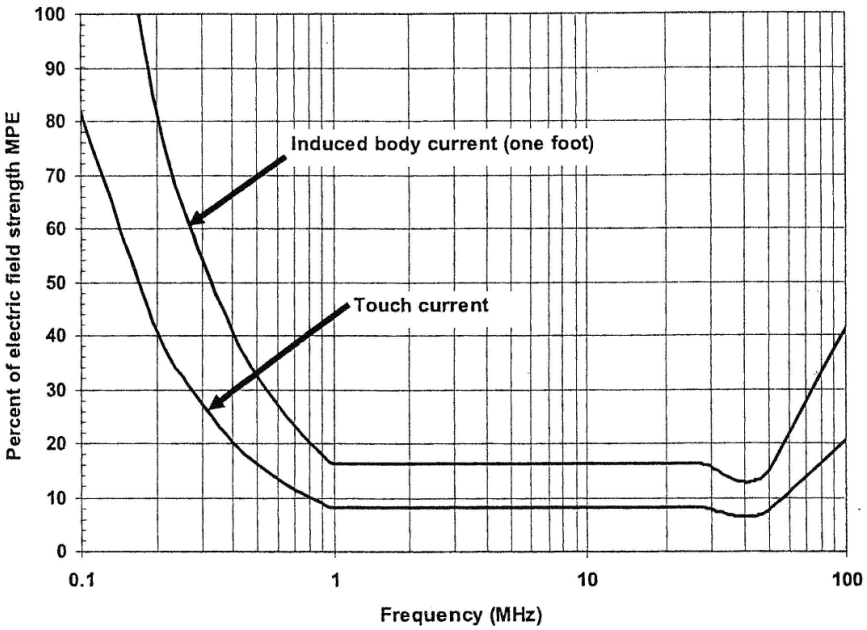

FIGURE 2. Percent of electric field strength TLVs® below which induced and contact current limits are *not* required from 0.1 to 100 MHz. (From IEEE Std. C95.1 – 2005a. Copyright © IEEE. All Rights Reserved).

TABLE 2. Major Frequency Ranges Covered by the TLV®

Part A – Frequency Range				
	30 kHz–100 kHz	**100 kHz–100 MHz**	**100 MHz–300 MHz***	**300 MHz–300 GHz**
Electric Field	X	X	X	
Magnetic Field	X	X	X	
Power Density			X	X
Contact Current	X	X†		

Part B – Hazard Mechanism				
	Electrical stimulation	**Thermal**		**Thermal**
Typical cause of injury	Contact current (current introduced into body from touching a charged conductor)	Contact current / possible RF heating of deeper tissues		RF heating of tissues
Typical injury	Electric shock (sometimes burns)	Burns (can be deep in tissue) Excessive whole body heating/ heat stress		
Example sources with potential overexposure	AM radio transmission tower	RF heat sealers and FM transmitting antennae	High-powered broadcasting transmitting antennae (e.g., TV)	Industrial microwave heating equipment, high-powered transmitting antennae

* Power density measurements should be made in the far field of the source; otherwise, measurements should be made of electric and magnetic field as appropriate.

† Measure contact current if the electric field is greater than the % of E-TLV® for that frequency (*see* Figure 2).

H^2, or S) incurred within each frequency interval should be determined and the sum of all such fractions should not exceed unity.

3. The TLVs® refer to values averaged over any 6-minute (0.1-h) period for frequencies less than 3 GHz, and over shorter periods for higher frequencies down to 10 seconds at 300 GHz, as indicated in Table 1, Part A.
4. At frequencies between 0.1 and 3 GHz, the TLVs® for electromagnetic field strengths may be exceeded if:
   a) the exposure conditions can be shown by appropriate techniques to produce SARs below 0.4 W/kg, as averaged over the whole body;
   b) the induced currents in the body conform with the TLVs® in Table 1, Part B; and
   c) spatial peak SAR values do not exceed 10 W/kg, as averaged over any cubic volume with 10 g of tissue, except for the hands, wrists, feet,

ankles, and pinnae, where the spatial peak SAR exposure should not exceed 20 W/kg averaged over any cubic volume of tissue containing 10 g. The SARs are to be averaged over 6 minutes.

5. Above 3 GHz, relaxation of the TLV® conditions may be permissible under partial body exposure conditions.
6. The measurement of RF field should follow the recommendations given in IEEE C95.3-2002 (IEEE, 2002) and Report No. 119 of the National Council on Radiation Protection and Measurements (NCRP, 1993).

References

Institute of Electrical and Electronic Engineers (IEEE): IEEE Recommended Practice for Measurements and Computations of Radiofrequency Electromagnetic Fields with Respect to Human Exposure to Such Fields, 100 kHz–300 GHz. IEEE C95.3-2002. IEEE, New York (2002).

Institute of Electrical and Electronic Engineers (IEEE): IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz. IEEE C95.1-2005. IEEE, New York (2005a).

National Council on Radiation Protection and Measurements (NCRP): A Practical Guide to the Determination of Human Exposures to Radiofrequency Fields. Report No 119. NCRP, Bethesda, MD (1993).

OPTICAL RADIATION

LIGHT AND NEAR-INFRARED RADIATION

These TLVs® refer to values for incoherent (non-laser) visible and near-infrared radiation (LNIR) in the wavelength region of 305 to 3000 nm that nearly all workers may be exposed without adverse health effects. The values are based on the best available information from experimental studies. They should be used only as guides in the control of exposures to light and should not be regarded as fine lines between safe and dangerous levels. For purposes of specifying these TLVs®, the optical radiation spectrum is divided into the regions shown in the figure "The Electromagnetic Radiation Spectrum and Related TLVs®" found at the beginning of the section on Electromagnetic Fields 0–300 GHz.

Recommended Values

The TLVs® for occupational exposure of the eyes to broadband light and near-infrared radiation apply to exposures in any 8-hour workday. Table 1 provides examples of sources and the applicable TLV®. Figure 1 is a guide to the application of the TLVs® for visible and near-infrared sources.

The LNIR TLVs® are divided into four potential health effects and spectral regions as follows:

Section 1. *To protect against retinal photo-chemical injury from chronic blue-light (305 < λ < 700 nm) exposure:* Determine the effective radiance of the light source (L_B) in W • cm^{-2} • sr^{-1} by integrating the spectral radiance (L_λ) in W • cm^{-2} • sr^{-1} • nm^{-1} weighted by the blue-light hazard function B(λ) using Equation 1 or a light meter with a B(λ) filter. B(λ) is shown in Figure 2 and values are provided in Table 2.

$$L_B\,[W \cdot cm^{-2} \cdot sr^{-1}] = \sum_{305}^{700} L_\lambda \cdot B(\lambda) \cdot \Delta\lambda \qquad \textbf{(1)}$$

Some meters provide a total energy emitted in units of J • cm^{-2} • sr^{-1} over the sampling period, which is the time integral of L_B over the sampling period. L_B is the total energy divided by the sample period.

For viewing durations (t) less than 10^4 s (167 mins or ~ 2.8 hrs) in a day, an acceptable exposure is present when:

$$L_B\,[W \cdot cm^{-2} \cdot sr^{-1}] \leq 100 \cdot t^{-1} \qquad \textbf{(2a)}$$

Alternatively, when L_B exceeds 0.01 W • cm^{-2} • sr^{-1}, the maximum acceptable exposure duration t_{max} in seconds is:

$$t_{max}\,[s] = 100(L_B)^{-1} \qquad \textbf{(2b)}$$

TABLE 1. Example Sources of Non-Laser Optical Radiation and Applicable TLVs®

*Source Type**	**Arc Sources**	**Discharge Lamps**	**Fluorescent Lamps and LEDs**	**Thermal Sources**	**Germicidal Lamps**
	Arc welding; Arc lamps; Xenon-arc searchlights		White-light and "black-light" fluorescent lamps; Visible or UV-A LEDs	Hot and molten metals; Gas welding; Incandescent lamps; IR LEDs	Low-pressure mercury discharge lamps; UV-B and UV-C lamps and LEDs
Ultraviolet *See* UV TLV®	♦♦	♦	♦		♦♦
Blue-Light *See* LNIR Section 1	♦♦	♦♦	♦		
IR Cornea/Lens *See* LNIR Section 2	♦	♦		♦♦	
Infrared Retina *See* LNIR Section 3	f	f		♦	
Retinal Thermal *See* LNIR Section 4	M				

♦♦ – Likely
♦ – Possible
f – Applicable when filtered lamp blocks visible emission
M – Only if magnified source size (e.g., searchlight or projection optics)
*A special type of diode emitter, the super-luminescent diode (SLD), although not a laser, should be assessed with the laser TLV®.