TLV®–PA

ELECTROMAGNETIC RADIATION SPECTRUM AND RELATED TLVS®

	Non-ionizing Radiation						Ionizing Radiation
Region*	**Sub-Radiofrequency**	**Radiofrequency**	**Microwave**	**Infrared**	**Light**	**Ultraviolet**	**X-ray**
Waveband	ELF			IR-C, IR-B, IR-A		UV-A, UV-B, UV-C	
Wavelength	1000 km	10 km	1 m	1 mm, 3 µm, 1.4 µm	760 nm	400 nm, 315 nm, 280 nm, 180 nm	100 nm
Frequency	300 Hz	30 kHz	300 MHz	300 GHz			
Applicable TLV®	**Sub-Radiofrequency**	**Radiofrequency and Microwave**		**Light and Near Infrared**; **Lasers**	**Light and Near Infrared**; **Lasers**	**Ultraviolet**; **Lasers**	**Ionizing Radiation**

*The boundaries between regions are set by convention and should not be regarded as absolute dividing lines.

ELECTROMAGNETIC RADIATION AND FIELDS

* STATIC MAGNETIC FIELDS

These TLVs® refer to static magnetic field flux densities to which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects. These values should be used as guides in the control of exposure to static magnetic fields and should not be regarded as fine lines between safe and dangerous levels.

Routine occupational exposures should not exceed 2 tesla (T) in the general workplace environment, but can have ceiling values of 8 T for workers with special training and operating in a controlled workplace environment. Special training involves making workers aware of transient sensory effects that can result from rapid motion in static magnetic fields with flux densities greater than 2 T. A controlled workplace environment is one in which forces exerted by static magnetic fields on metallic objects do not create potentially hazardous projectiles. Exposure of the limbs of workers in the general workplace environment should not exceed 20 T. Workers with implanted ferromagnetic or electronic medical devices should not be exposed to static magnetic fields exceeding 0.5 mT.

These TLVs® are summarized in Table 1.

TABLE 1. TLVs® for Static Magnetic Fields

Exposure	Ceiling Value
Whole body (general workplace)	2 T
Whole body (special worker training and controlled workplace environment)	8 T
Limbs	20 T
Medical device wearers	0.5 mT

SUB-RADIOFREQUENCY (30 kHz and below) MAGNETIC FIELDS

These TLVs® refer to the amplitude of the magnetic flux density (B) of sub-radiofrequency (sub-RF) magnetic fields in the frequency range of 30 kilohertz (kHz) and below to which it is believed that nearly all workers may be exposed repeatedly without adverse health effects. The magnetic field strengths in these TLVs® are root-mean-square (rms) values. These values should be used as guides in the control of exposure to sub-radiofrequency magnetic fields and should not be regarded as fine lines between safe and dangerous levels.

Occupational exposures in the extremely-low-frequency (ELF) range from 1 to 300 hertz (Hz) should not exceed the ceiling value given by the equation:

$$B_{TLV} = \frac{60}{f}$$

where: f = the frequency in Hz

B_{TLV} = the magnetic flux density in millitesla (mT).

For frequencies in the range of 300 Hz to 30 kHz (which includes the voice frequency [VF] band from 300 Hz to 3 kHz and the very-low-frequency [VLF] band from 3 to 30 kHz), occupational exposures should not exceed the ceiling value of 0.2 mT.

These ceiling values for frequencies of 300 Hz to 30 kHz are intended for both partial-body and whole-body exposures. For frequencies below 300 Hz, the TLV® for exposure of the extremities can be increased by a factor of 10 for the hands and feet and by a factor of 5 for the arms and legs.

The magnetic flux density of 60 mT/f at 60 Hz corresponds to a maximum permissible flux density of 1 mT. At 30 kHz, the TLV® is 0.2 mT, which corresponds to a magnetic field intensity of 160 amperes per meter (A/m).

Contact currents from touching ungrounded objects that have acquired an induced electrical charge in a strong sub-RF magnetic field should not exceed the following point contact levels to avoid startle responses or severe electrical shocks:

A. 1.0 milliampere (mA) at frequencies from 1 Hz to 2.5 kHz;

B. 0.4f mA at frequencies from 2.5 to 30 kHz, where f is the frequency expressed in kHz.

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.

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: 0.4f mA where: f = frequency in kHz

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

These TLVs® refer to the maximum unprotected 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 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, due to individual susceptibility, 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) from 0 hertz (Hz) (direct current [DC]) to 100 Hz. For frequencies in the range of 100 to 4 kilohertz (kHz), the ceiling value is given by:

$$E_{TLV} = \frac{2.5 \times 10^6}{f}$$

where: f = the frequency in Hz

E_{TLV} = the electric field strength in volts per meter (V/m)

A value of 625 V/m is the ceiling value for frequencies from 4 to 30 kHz. These ceiling values 0 to 30 kHz are intended for both partial-body and whole-body exposures.

Contact currents from touching ungrounded objects that have acquired an electrical charge in a strong static or sub-RF electric field should not exceed the following point contact levels to avoid startle responses or severe electrical shocks:

A. 1.0 mA at frequencies from 0 to 2.5 kHz;

B. 0.4f mA at frequencies from 2.5 to 30 kHz, where f is the frequency expressed in kHz.

Notes:

1. These TLVs® are based on limiting currents on the body surface and induced internal currents to levels below those that are believed to produce adverse health effects. Certain biological effects have been demonstrated 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 these 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.

2. Field strengths greater than approximately 5 to 7 kV/m can produce a wide range of safety hazards such as startle reactions associated with spark discharges and contact currents from ungrounded conductors within the field. In addition, safety hazards associated with combustion, ignition of flammable materials, and electro-explosive devices may exist when a high-intensity electric field is present. Care should be taken to eliminate ungrounded objects, to ground such objects, or to use insulated gloves when ungrounded objects must be handled. Prudence dictates the use of protective devices (e.g., suits, gloves, and insulation) in all fields exceeding 15 kV/m.
3. For workers with 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) electric fields as low as 2 kV/m. It is recommended that, lacking specific information on electromagnetic interference from the manufacturer, the exposure of pacemaker and medical electronic device wearers should be maintained at or below 1 kV/m.

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

Frequency Range	TLV®
0 to 100 Hz	25,000 V/m in air (ceiling value)
100 Hz to 4 kHz	$\frac{2.5 \times 10^6}{f}$ V/m in air (ceiling value) where: f = frequency in Hz
4 to 30 kHz	625 V/m in air (ceiling value)
0 to 2.5 kHz	Point contact current limit: 1.0 mA
2.5 to 30 kHz	Point contact current limit: 0.4f mA where: f = frequency in kHz

NOTICE OF INTENDED CHANGE —
† SUB-RADIOFREQUENCY (30 kHz and below) and STATIC ELECTRIC FIELDS

The reason for this NIC is to modify ramp in TLV® ceiling values at frequencies from 220 Hz to 3 kHz; ceiling values from 3 to 30 kHz have been increased to match the electric field TLV® at 30 kHz in the Radiofrequency and Microwave Radiation TLVs®; and the "Other Exposure Guidelines" section has been deleted.

These TLVs® refer to the maximum unprotected 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 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, due to individual susceptibility, 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) from 0 hertz (Hz) (direct current [DC]) to 220 Hz. For frequencies in the range of 220 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 currents on the body surface and induced internal currents to levels below those that are believed to produce adverse health effects. Certain biological effects have been demonstrated 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 these 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.
2. Field strengths greater than approximately 5 to 7 kV/m can produce a wide range of safety hazards such as startle reactions associated with spark

TLV®–PA

discharges and contact currents from ungrounded conductors within the field. In addition, safety hazards associated with combustion, ignition of flammable materials, and electro-explosive devices may exist when a high-intensity electric field is present. Care should be taken to eliminate ungrounded objects, to ground such objects, or to use insulated gloves when ungrounded objects must be handled. Prudence dictates the use of protective devices (e.g., suits, gloves, and insulation) in all fields exceeding 15 kV/m.

3. For workers with 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) electric fields as low as 2 kV/m. It is recommended that, lacking specific information on electromagnetic interference from the manufacturer, the exposure of pacemaker and medical electronic device wearers should be maintained at or below 1 kV/m.

‡ RADIOFREQUENCY AND MICROWAVE RADIATION

These TLVs® refer to radiofrequency (RF) and microwave radiation in the frequency range of 30 kilohertz (kHz) to 300 gigahertz (GHz) and represent conditions under which it is believed nearly all workers may be repeatedly exposed without adverse health effects. The TLVs®, 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 which can be associated with exposure to such fields, are given in Table 1 and Figure 1 as a function of frequency, f, in megahertz (MHz).

A. The 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 value remains within the specified limits. The TLVs® may also be relaxed by reference to specific absorption rate (SAR) limits by appropriate calculations or measurements.

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 each foot, should not exceed the following values:

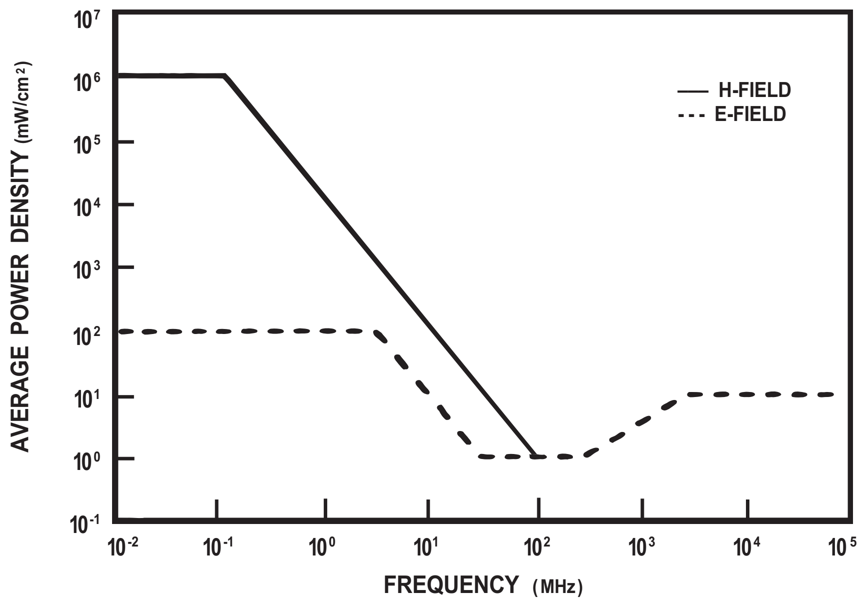

FIGURE 1. Threshold Limit Values (TLVs®) for Radiofrequency/Microwave Radiation in the workplace (whole-body specific absorption rate [SAR] < 0.4 W/kg).

I = 1000f mA for (0.03 < f < 0.1 MHz) averaged over 1 second
I = 100 mA for (0.1 < f < 100 MHz) averaged over 6 minutes, subject to a ceiling value of 500 mA

where: mA = milliampere

2. For conditions of possible contact with metallic bodies, maximum RF current through an impedance equivalent to that of the human body for conditions of grasping contact as measured with a contact current meter should not exceed the following values:

I = 1000f mA for (0.03 < f < 0.1 MHz) averaged over 1 second
I = 100 mA for (0.1 < f < 100 MHz) averaged over 6 minutes, subject to a ceiling value of 500 mA

TABLE 1. Radiofrequency and Microwave TLVs®

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

Frequency	Power Density, S (mW/cm^2)	Electric Field Strength, E (V/m)	Magnetic Field Strength, H (A/m)	Averaging Time E^2, H^2 or S (minutes)
30 kHz–100 kHz		614	163	6
100 kHz–3 MHz		614	16.3/f	6
3 MHz–30 MHz		1842/f	16.3/f	6
30 MHz–100 MHz		61.4	16.3/f	6
100 MHz–300 MHz	1	61.4	0.163	6
300 MHz–3 GHz	f/300			6
3 GHz–15 GHz	10			6
15 GHz–300 GHz	10			$616{,}000/f^{1.2}$

[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).

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

Frequency	Through Both Feet	Through Either Foot	Contact	Averaging Time
30 kHz–100 kHz	2000f	1000f	1000f	1 second[C]
100 kHz–100 MHz	200	100	100	6 minutes[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. See text for additional comment.

[C] **I** is averaged over any 1-second period.

[D] **I** is averaged over a 6-minute period (e.g., for either foot or hand contact, **I** t ≤ 60,000 mA^2-minutes, subject to a ceiling limit of 500 mA).

3. 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 prohibition of metallic objects, or training of personnel may be sufficient to ensure compliance with this aspect of the TLVs®. Evaluation of the magnitude of the induced currents normally will require a direct measurement. However, induced and contact current measurements are not necessary if the spatially averaged electric-field-strength limit found in Section A does not exceed the TLV® at frequencies between 0.1 and 0.45 MHz and does not exceed the limits shown in Figure 2 at frequencies greater than 0.45 MHz.

C. For near-field exposures at frequencies less than 300 MHz, the applicable TLV® is in terms of rms electric and magnetic field strength, as given in Table 1, Part A. Equivalent plane-wave power density, S (in mW/cm^2), can be calculated from the field strength measurement data as follows:

$$S = \frac{E^2}{3770}$$

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

$$S = 37.7\ H^2$$

where: H^2 is in amperes squared (A^2) per meter squared (m^2). Figure 3 can assist the user of the TLV® in making E, H, and current measurements in the correct order of precedence.

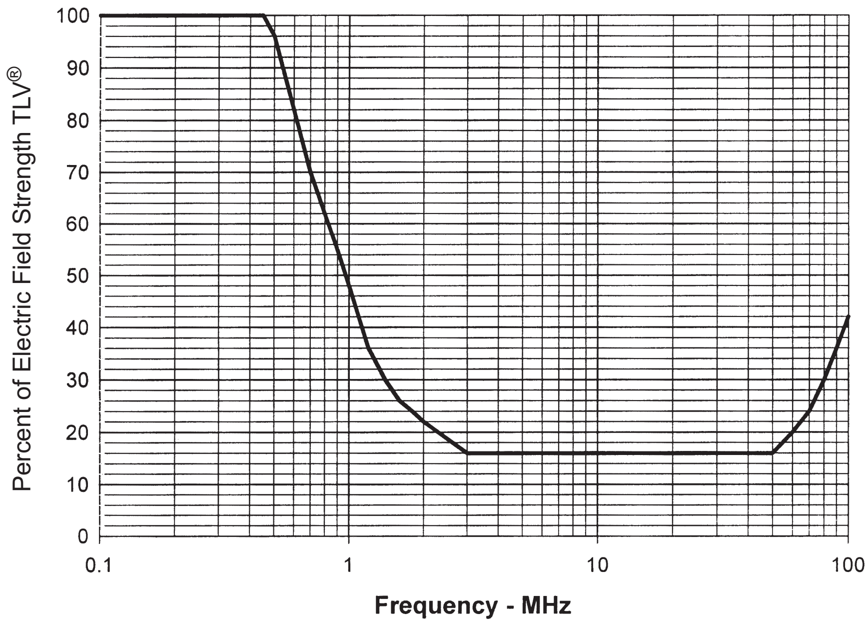

FIGURE 2. Percent of electric field strength TLVs® below which induced and contact current limits are *not* required from 0.1 to 100 MHz. (From IEEE Std C95.1-1999.[2] Copyright © 1999 IEEE. All rights reserved.)

TLV®–PA

D. For exposures to pulsed fields of pulse duration less than 100 milliseconds (msec) and frequencies in the range of 100 kHz to 300 GHz, the TLV® in terms of peak power density for a single pulse is given by the TLV® in Table 1, Part A, multiplied by the averaging time in seconds and divided by 5 times the pulse width in seconds, that is:

$$\text{Peak TLV} = \frac{\text{TLV} \times \text{Avg. Time (sec)}}{5 \times \text{Pulse width (sec)}}$$

A maximum of five such pulses may be permitted during any period equal to the averaging time. If there are more than 5 pulses during any period equal to the averaging time, then the peak TLV® is limited by the normal time-averaging process. For pulse durations greater than 100 msec, normal time-averaging calculations apply.

These values 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.

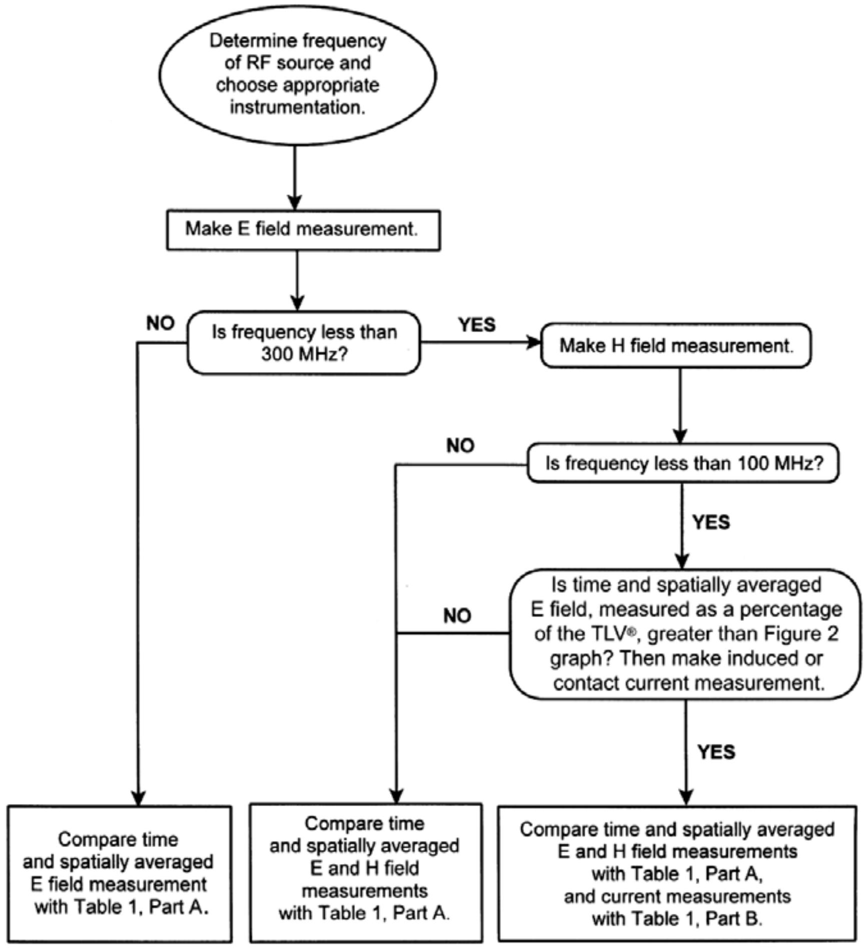

FIGURE 3. Flowchart for making E, H, and current measurements in the correct order of precedence.

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 will 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, 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-hour) period for frequencies less than 15 GHz and over shorter periods for higher frequencies down to 10 seconds at 300 GHz, as indicated in Table 1.
4. At frequencies between 100 kHz and 1.5 GHz, the TLV® may be exceeded if:
   - The radiated power is $\leq$ 7 W for frequencies from 100 kHz to 450 MHz.
   - The radiated power is $\leq$ 7(450/f) for frequencies of 450 MHz through 1500 MHz.

   This exclusion does not apply to devices that are attached to the body on a continual basis. Radiated power means the power radiated from the antenna into free space in the absence of any nearby objects.

5. At frequencies between 100 kHz and 6 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, and spatial peak SAR values not exceeding 8 W/kg, as averaged over any 1 gram of tissue (defined as a tissue volume in the shape of a cube), except for the hands, wrists, feet, and ankles, where the spatial peak SAR should not exceed 20 W/kg, as averaged over any 10 grams of tissue (defined as a tissue volume in the shape of a cube), and b) the induced currents in the body conform with the guide in Table 1. The SARs are averaged over any 6 minutes. Above 6 GHz, relaxation of the TLVs® under partial body exposure conditions may be permitted. Recognition must be given to regions of the body where a 1- or 10-cubic centimeter volume would contain a mass significantly less than 1 or 10 grams, respectively, because of enclosed voids (air). For these regions, the absorbed power should be divided by the actual mass with that volume to obtain the spatial peak SARs.

   At frequencies between 0.03 and 0.1 MHz, the SAR exclusion, stated above, does not apply. However, the TLV® may still be exceeded if it can be shown that the peak rms current density, as averaged over a 1 cm^2 area of tissue and 1 second, does not exceed 35f mA/cm^2, where f is the frequency in MHz.
6. The measurement of RF field strength depends upon several factors, including probe dimensions and distance of the source from the probe. Measurement procedures should follow the recommendations given in IEEE C95.1-1999[1] and NCRP Report No. 119.[3]
7. All exposures should be limited to a maximum (peak) electric field intensity of 100 kV/m.
8. Ultrawideband radiation (UWB) is a relatively new modality used for imaging, wireless communications (voice, data, and video), identification tags, security systems, and other applications. UWB signals consist of short pulses (usually < 10 nanosecond [ns]) and fast rise time (< 200 picoseconds [ps]) that result in a very wide bandwidth. For practical purposes, UWB can be considered as a signal that has a bandwidth greater than the central frequency. The following is a set of guidelines for human exposure to UWB radiation that follow the recommendations of the Tri-Service Electromagnetic Radiation Panel issued in June 1997.

   For a UWB pulse, the specific absorption rate (SAR) expressed in W/kg of tissue is given by

$$SAR = S \times PW \times PRF \times 0.25$$

   where: S = equivalent plane-wave power density (mW/cm^2)
   PW = effective pulse width (sec), including the ring-down time
   PRF = pulse repetition frequency (sec^{-1})
   0.25 = maximum normalized SAR (W/kg) per mW/cm^2 in the human body exposed to a 70-MHz RF field

   Exposure limitations are considered for two conditions: *(A)* UWB exposure greater than 6 minutes and *(B)* UWB exposure less than 6 minutes with an SAR greater than 0.4 W/kg, the whole-body limit allowed by the IEEE C95.1 standard for RF radiation issued in 1991 and revised in 1999.

Condition A: For exposures greater than 6 minutes, the SAR is limited to 0.4 W/kg, averaged over any 6-minute period, corresponding to a specific absorption (SA) of 144 J/kg for 6 minutes. The permitted PRF for a UWB pulse is given by the following:

$$\mathrm{PRF(sec^{-1})} = \frac{\text{144 J/kg}}{\text{(SA in J/kg per pulse)(360 sec)}}$$

Condition B: The conservative assumption is made that the permissible exposure time (ET) is inversely proportional to the square of the SAR in W^2/kg^2. ET is then given by the following equation:

$$\mathrm{ET(sec)} = \frac{(0.4\ \mathrm{W/kg} \times 144\ \mathrm{J/kg})}{(\mathrm{SAR})^2} = \frac{57.6}{(\mathrm{SAR})^2}$$

References

1. Institute of Electrical and Electronics Engineers: IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz. IEEE Standard C95.1-1999 (incorporating IEEE Std. C95.1-1991 and IEEE Std. C95.1a-1998). IEEE, New York (April 16, 1999).
2. Institute of Electrical and Electronics Engineers: Figure 2 reprinted with permission from IEEE Std C95.1-1999 “IEEE Standard for Safety Levels with Respect to Human Exposure to Radiofrequency Electromagnetic Fields, 3 kHz to 30 GHz.” Copyright (c) 1999 by IEEE. The IEEE disclaims any responsibility or liability resulting from the placement and use in the described manner.
3. National Council on Radiation Protection and Measurements: A Practical Guide to the Determination of Human Exposure to Radiofrequency Fields. Report No. 119. NCRP, Bethesda, MD (1993).

NOTICE OF INTENDED CHANGE — † RADIOFREQUENCY AND MICROWAVE RADIATION

The reason for this NIC is to add Note 9 to the TLV®; to add the section entitled "Radiofrequency Interference Effects on Equipment and Medical Devices" to the *Documentation*; to update the TLV®; and to present the TLV® units in W/m^2 instead of W/cm^2.

These TLVs® refer to radiofrequency (RF) and microwave radiation in the frequency range of 30 kilohertz (kHz) to 300 gigahertz (GHz) and represent conditions under which it is believed nearly all workers may be repeatedly exposed without adverse health effects. The TLVs®, 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 that can be associated with exposure to such fields, are given in Table 1 as a function of frequency (f) in megahertz (MHz).

A. The 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 value remains within the specified limits. The TLVs® may also be relaxed by reference to specific absorption rate (SAR) limits by appropriate calculations or measurements.

B. Access should be restricted to limit the rms RF body current and potential for RF electrostimulation (Ashock", 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:

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

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

2. For conditions of possible contact with metallic bodies, maximum RF current through an impedance equivalent to that of the human body for conditions of grasping contact as measured with a contact current meter should not exceed the following values:

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

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

3. For touch contact with conductive objects, the maximum RF current should not exceed more than one-half 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 near-field exposures at frequencies less than 300 MHz, the applicable TLV® is given in terms of rms electric and magnetic field strength, as shown in Table 1, Part A. Equivalent plane-wave power density, S (in W/m^2) 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). Figure 3 can assist the user of the TLV® in making E, H, and current measurements in the correct order of precedence.

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 maximum value of the instantaneous E field is 100 kV/m. 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 x 144 = 28.8 J/kg. For pulse durations greater than 100 ms, normal time-averaging calculations apply.

TLV®–PA

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–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 MHz–30 GHz	100			$33{,}878.2/f^{1.079}$
30 GHz–300 GHz	100			$67.62/f^{0.476}$

[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 above 30 GHz, the power density TLV® is the limit over any contiguous 0.01 m^2 of body surface.

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

Frequency	Through Both Feet	Through Either Foot	Grasping	Averaging Time
30 kHz–100 kHz	2000f	1000f	1000f	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. Maximum touch current is limited to 50% of the maximum grasping current. The ceiling value for induced and contact currents is 500 mA.

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

[D] **I** is averaged over a 6-min period (e.g., for either foot or hand contact, i.e., **I** t ≤60,000 mA^2-min).

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.

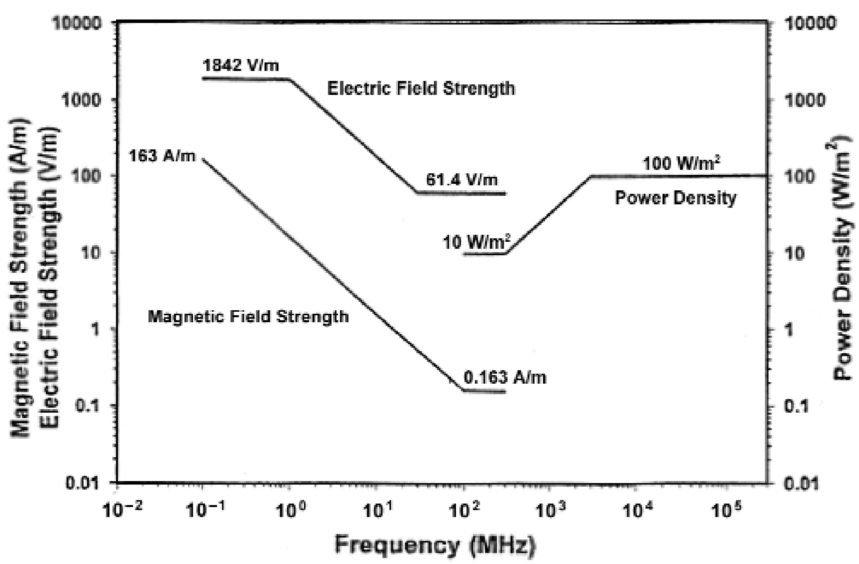

FIGURE 1. Threshold Limit Values (TLVs®) for Radio-frequency/Microwave Radiation in the workplace (for whole-body specific absorption rate [SAR] < 0.4 W/kg). Reprinted with permission of IEEE, Std. C95.1–2005.

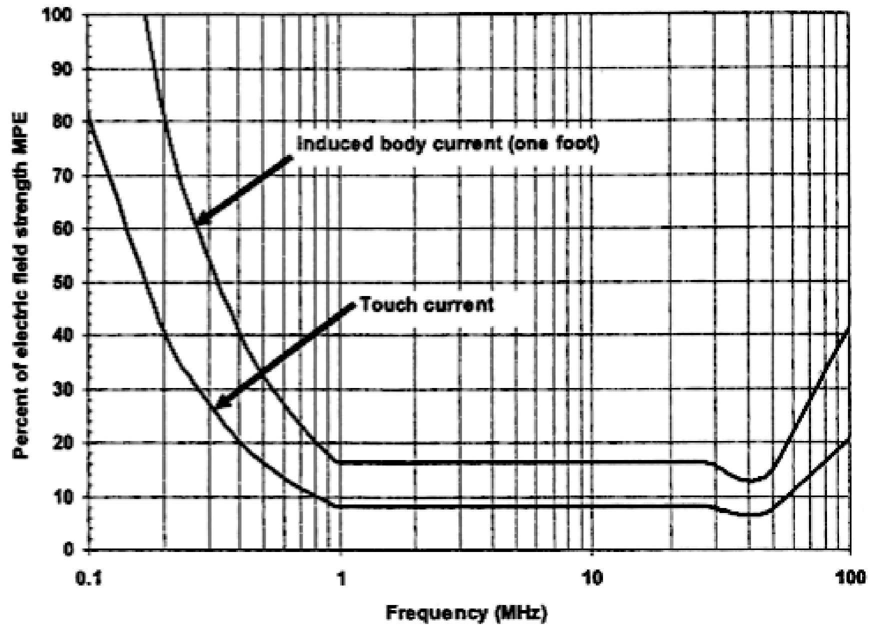

FIGURE 2. Percent of electric field strength TLVs® below which induced and contact current limits are *not* required from 0.1 to 100 MHz. Reprinted with permission of IEEE from Std. C95.1 – 2005.

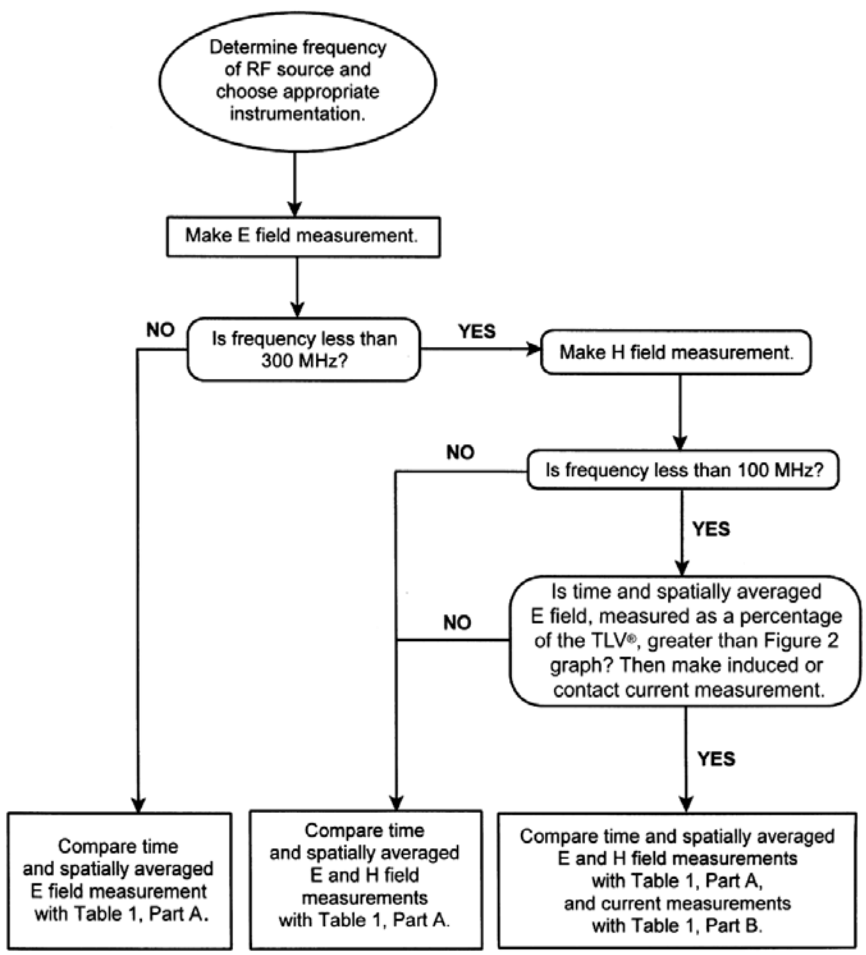

FIGURE 3. Flowchart for making E, H, and current measurements in the correct order of precedence.

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 will 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, 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 six-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 min. Recognition should be given to regions of the body where a 10 cm^3 volume may have a mass significantly less than 10 g because of enclosed voids containing air. In these regions, the absorbed power should be divided by the actual mass to determine spatial peak SARs.
5. Above 3 GHz, relaxation of the TLV® conditions may be permissible under partial body exposure conditions.
6. The measurement of RF field strength depends upon several factors, including probe dimensions and distance of the source from the probe. Measurement procedures 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).
7. All exposures should be limited to a maximum (peak) electric field intensity of 100 kV/m.
8. Ultrawideband radiation (UWB) is a relatively new modality used for imaging, wireless communications (voice, data, and video), identification tags, security systems, and other applications. UWB signals consist of short pulses (usually < 10 nanosecond [ns]) and fast rise time (< 200 picoseconds [ps]) that result in a very wide bandwidth. For practical purposes, UWB can be considered as a signal that has a bandwidth greater than the central frequency. The following is a set of guidelines for human exposure to UWB radiation that follow the recommendations of the Tri-Service Electromagnetic Radiation Panel (1996). For a UWB pulse, the specific absorption rate (SAR) expressed in W/kg of tissue is given by:

$$SAR = S \times PW \times PRF \times 0.25$$

where: S = equivalent plane-wave power density (W/m^2)

PW = effective pulse width (s), including the ring-down time
PRF = pulse repetition frequency (s^{-1}); and
0.025 = maximum normalized SAR (W/kg) per W/m^2 in the human body exposed to a 70-MHz RF field

Exposure limitations are considered for two conditions: *(A)* UWB exposure > 6 minutes and *(B)* UWB exposure < 6 minutes with an SAR > 0.4 W/kg, the whole-body limit allowed by the IEEE C95.1 standard for RF radiation issued in 1991 and revised in 1999 and 2005.

Condition A: For exposures > 6 minutes, the SAR is limited to 0.4 W/kg, averaged over any 6-minute period, corresponding to an SA value of 144 J/kg for 6 min. The permitted PRF for a UWB pulse is given by the following:

$$\mathrm{PRF}(\mathrm{s}^{-1}) = \frac{144\ \mathrm{J/kg}}{(\mathrm{SA\,in\ J/kg\ per\ pulse})(360\ \mathrm{s})}$$

Condition B: The conservative assumption is made that the permissible exposure time (ET) is inversely proportional to the square of the SAR in W^2/kg^2. ET is then given by the following equation:

$$\mathrm{ET}\,(\mathrm{s}) = \frac{(0.4\ \mathrm{W/kg} \times 144\ \mathrm{J/kg})}{(\mathrm{SAR})^2} = \frac{57.6}{(\mathrm{SAR})^2}$$

9. Many devices used in medicine, manufacturing, telecommunications, and transportation are highly sensitive to interference by exposure to radiofrequency fields (RFI). This problem has increased as a result of the rapid growth in the use of wireless communication devices, such as cellular telephones, handheld transceivers, and vehicle-mounted transceivers. The U.S. Food and Drug Administration's Center for Devices and Radiological Health has made a major effort to inform manufacturers of the need to make medical devices immune to RFI effects to the maximum extent possible. However, RFI problems continue to be identified and can adversely affect the operation of cardiac pacemakers, defibrillators, drug infusion pumps, apnea monitors, and a variety of other medical devices such as electrically powered wheelchairs. For these devices, the TLVs® may not protect against RFI. The use of sensitive medical equipment or the entry of individuals wearing medical electronic devices subject to RFI should be restricted to locations where the levels of RF-microwave fields at frequencies up to 3 GHz are not expected to interfere with operation of medical devices based on manufacturers' specifications (typically field levels below 3 to 10 V/m that meet compliance requirements for immunity to RFI).

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).

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).

Tri-service Electromagnetic Radiation Panel: Ultra-wideband (UWB) Interim Guidance. Approved May 1996. Available from Brooks Air Force Base, San Antonio, Texas (1996).

LIGHT AND NEAR-INFRARED RADIATION

These TLVs® refer to values for incoherent (non-laser) visible and near-infrared radiation 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 on page 124.

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. Figure 1 is a guide to the application of the TLVs® for visible and near infrared sources.

The first step is to determine if there is a broadband source including the visible light spectrum of sufficient luminance to consider the visible light contributions. If the luminance is greater than 1 candela per square centimeter (cd/cm^2), then the TLVs® in Sections 1 and 2 apply. With a low luminance and no special sources involved, there may not be a significant risk. If the source has a high blue light component such as a blue light-emitting diode (LED), then Section 2 applies. If the source is primarily in the near infrared range because it uses special filters or is in the range by nature (e.g., LED), then Sections 3 and 4 apply. The TLVs® are divided into four potential health effects and spectral regions as follows:

Section 1. *To protect against retinal thermal injury from a visible light source:* Determine the effective spectral radiance of the lamp (L_R) in W/(cm^2 sr) [sr = steradian] by integrating the spectral radiance (L_λ) in W/(cm^2 sr nm) weighted by the thermal hazard function $R(\lambda)$, using Equation 1 or a light meter with an $R(\lambda)$ filter. $R(\lambda)$ is shown in Figure 2 and values are provided in Table 1.

TLV®–PA

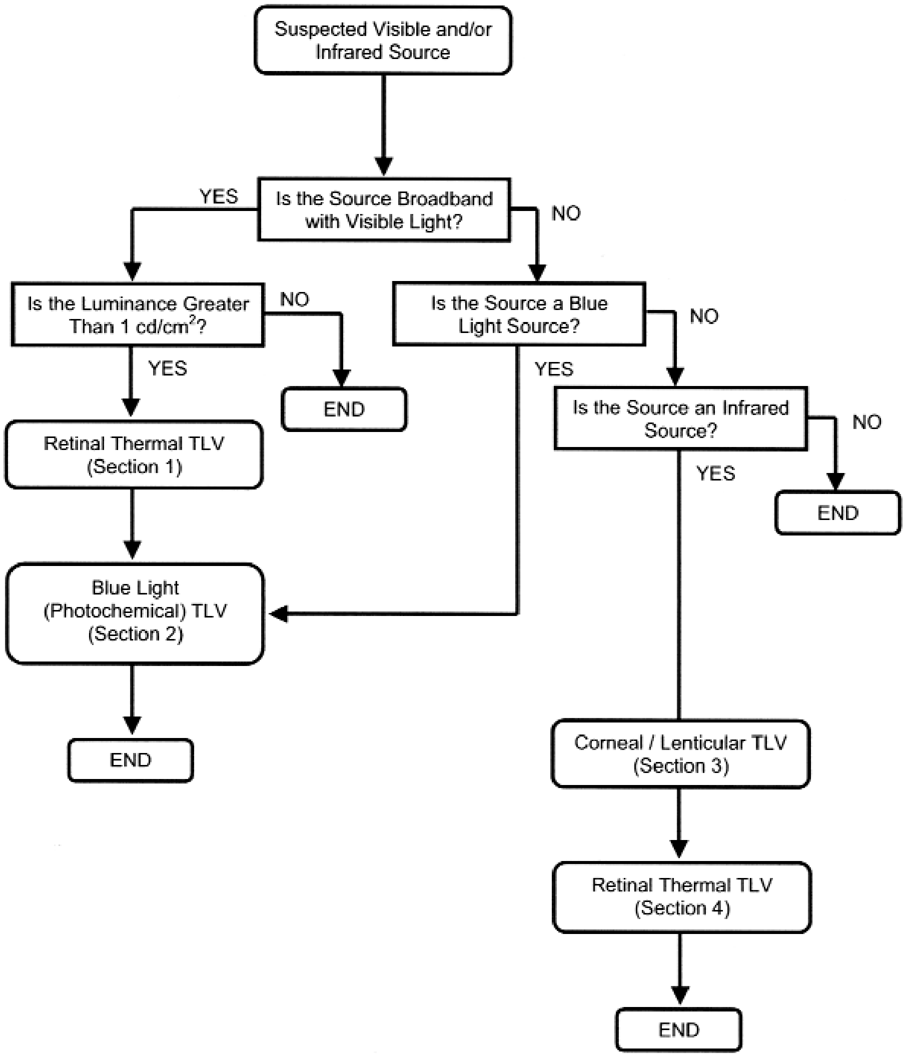

FIGURE 1. Evaluation scheme for visible and near infrared radiation.

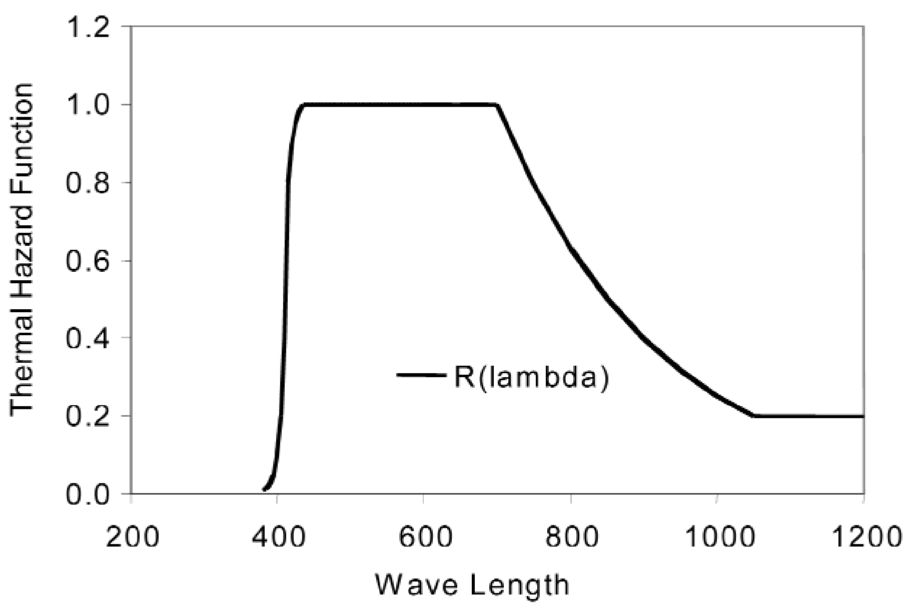

FIGURE 2. Retinal thermal hazard function [R(λ)].

TABLE 1. Retinal and UVR Hazard Spectral Weighting Functions

Wavelength (nm)	Aphakic Hazard Function A(λ)	Blue-Light Hazard Function B(λ)	Retinal Thermal Hazard Function R(λ)
305–335	6.00	0.01	—
340	5.88	0.01	—
345	5.71	0.01	—
350	5.46	0.01	—
355	5.22	0.01	—
360	4.62	0.01	—
365	4.29	0.01	—
370	3.75	0.01	—
375	3.56	0.01	—
380	3.19	0.01	0.01
385	2.31	0.0125	0.0125
390	1.88	0.025	0.025
395	1.58	0.050	0.050
400	1.43	0.100	0.100
405	1.30	0.200	0.200
410	1.25	0.400	0.400
415	1.20	0.800	0.800
420	1.15	0.900	0.900
425	1.11	0.950	0.950
430	1.07	0.980	0.980
435	1.03	1.000	1.00
440	1.000	1.000	1.00
445	0.970	0.970	1.00
450	0.940	0.940	1.00
455	0.900	0.900	1.00
460	0.800	0.800	1.00
465	0.700	0.700	1.00
470	0.620	0.620	1.00
475	0.550	0.550	1.00
480	0.450	0.450	1.00
485	0.400	0.400	1.00
490	0.220	0.220	1.00
495	0.160	0.160	1.00
500	0.100	0.100	1.00
505	0.079	0.079	1.00
510	0.063	0.063	1.00
515	0.050	0.050	1.00
520	0.040	0.040	1.00
525	0.032	0.032	1.00
530	0.025	0.025	1.00
535	0.020	0.020	1.00
540	0.016	0.016	1.00
545	0.013	0.013	1.00
550	0.010	0.010	1.00
555	0.008	0.008	1.00
560	0.006	0.006	1.00
565	0.005	0.005	1.00
570	0.004	0.004	1.00
575	0.003	0.003	1.0

TABLE 1 (con't.). Retinal and UVR Hazard Spectral Weighting Functions

Wavelength (nm)	Aphakic Hazard Function A(λ)	Blue-Light Hazard Function B(λ)	Retinal Thermal Hazard Function R(λ)
580	0.002	0.002	1.0
585	0.002	0.002	1.0
590	0.001	0.001	1.0
595	0.001	0.001	1.0
600–700	0.001	0.001	1.0
700–1050	—	—	$10^{[(700-\lambda)/500]}$
1050–1400	—	—	0.2

$$L_R\,[\mathrm{W/(cm2sr)}] = \sum_{380}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda \qquad (1)$$

Some meters provide a total energy emitted in units of J/(cm^2 sr) over the sampling period, which is the time integral of L_R over the sampling period. Therefore, an alternative expression of the retinal thermal injury TLV® is a dose limit (called DL_R in this TLV®).

Determine the angular subtense (α) of the source in radians (rad). For circular lamps, α is the lamp diameter divided by the viewing distance. If the lamp is oblong, α is estimated from the mean of the shortest and longest dimension that can be viewed divided by the viewing distance, which is according to Equation 2.

TLV®–PA

$$\alpha\,[\mathrm{rad}] = \frac{(l + w)}{2r} \qquad (2)$$

For instance, at a viewing distance r = 100 cm from a 0.8-cm diameter tubular flash lamp of length l = 5 cm, the viewing angle α is 0.029 rad.

Large sources are those with an angular subtense (α) greater than 0.1 rad. For large sources, Equations 3a through 3c define the TLV® for protection against retinal thermal injury depending on the exposure duration (t) in seconds [s]. These limits also serve as a useful screening step.

For viewing durations (t) from 1 μs (10^{-6} s) through 0.00063 s, an acceptable exposure is present when Equation 3a is true. For pulse durations less than 1 μs, the TLV® is the same as that for 1 μs. Since the retinal thermal hazard TLVs® for pulsed sources assume a 7-mm, dark-adapted pupil, this exposure limit may be modified for daylight conditions.

$$L_R\,[\mathrm{W/(cm^2\,sr)}] \le \frac{640}{t^{1/4}} \quad \text{OR}$$

$$DL_R\,[\mathrm{J/(cm^2\,sr)}] \le 640 \cdot t^{0.75} \qquad (3a)♦$$

For viewing durations between 0.63 ms (0.00063 s) and 0.25 s, an acceptable exposure is present when Equation 3b is true.

$$L_R\,[\mathrm{W/(cm^2\,sr)}] \leq \frac{16}{t^{0.75}} \quad \text{OR}$$

$$DL_R\,[\mathrm{J/(cm^2\,sr)}] \leq 16 \cdot t^{1/4} \qquad (3b)♦$$

For viewing durations greater than 0.25 s, an acceptable exposure is present when Equation 3c is true. This is a rate-, rather than dose-, limited threshold.

$$L_R\,[\mathrm{W/(cm^2\,sr)}] \leq 45 \qquad (3c)♦$$

Small sources have an angular subtense (α) less than 0.1 rad. For small sources, the retinal thermal injury risk depends on both the exposure duration (t) and α. The interaction is a maximum value for α (α_{max}) as a function of viewing duration (t [s]).

For viewing durations from 1 µs (10^{-6} s) through 0.00063 s, an acceptable exposure is present when Equation 3a above is true. For pulse durations less than 1 µs, the TLV® is the same as that for 1 µs. Since the retinal thermal hazard TLVs® for pulsed sources assume a 7-mm, dark-adapted pupil, this exposure limit may be modified for daylight conditions.

For viewing durations from 0.00063 to 0.25 s, an acceptable exposure is present when Equation 4a is true.

With $\alpha < \alpha_{max} = 0.2 \cdot t^{0.5}$ rad,

$$L_R\,[\mathrm{W/(cm^2\,sr)}] \leq \frac{3.2}{\alpha \cdot t^{1/4}} \quad \text{OR}$$

$$DL_R\,[\mathrm{J/(cm^2\,sr)}] \leq \frac{3.2 \cdot t^{0.75}}{\alpha} \qquad (4a)♦$$

For viewing durations greater than 0.25 s, an acceptable exposure is present when Equation 4b is true. This is a rate-limited exposure and a dose limit does not apply.

With $\alpha < \alpha_{MAX} = 0.1$ rad,

$$L_R\,[\mathrm{W/(cm^2\,sr)}] \leq \frac{4.5}{\alpha} \qquad (4b)♦$$

Note: There may be special individual circumstances where the pupil remains dilated (tonic) and exposures extend beyond 0.25 s. Under these conditions, Equation 4c is the limiting exposure.

With $\alpha < \alpha_{MAX} = 0.1$ rad,

$$L_R\,[\mathrm{W/(cm^2\,sr)}] \leq \frac{3.2}{\alpha \cdot t^{1/4}} \qquad (4c)♦$$

Section 2. *To protect against retinal photochemical injury from chronic blue-light (305 < λ < 700 nm) exposure:* Determine the integrated effective spectral radiance of the light source (L_B) in W/(cm^2 sr) by integrating the spectral radiance (L_λ) in W/(cm^2 sr nm) weighted by the blue-light hazard function B(λ) using Equation 5 or a light meter with a B(λ) filter. B(λ) is shown in Figure 3 and values are provided in Table 1.

$$L_B\,[\mathrm{W/(cm^2\,sr)}] = \sum_{305}^{700} L_\lambda \cdot B(\lambda) \cdot \Delta\lambda \tag{5}$$

Some meters provide a total energy emitted in units of J/(cm^2 sr) 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 min or ~ 2.8 h) in a day, an acceptable exposure is present when:

$$L_B \leq \frac{100\,[\mathrm{J/(cm^2\,sr)}]}{t[\mathrm{s}]} \tag{6a}$$

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

$$t_{max}\,[\mathrm{s}] = \frac{100\,[\mathrm{J/(cm^2\,sr)}]}{L_B} \tag{6b}$$

For viewing durations greater than 10^4 s (167 min) in a day, an acceptable exposure is present when:

$$L_B\,[\mathrm{W/(cm^2\,sr)}] \leq 10^{-2} \tag{6c}$$

Note for blue light hazard: The L_B limits are greater than the maximum permissible exposure limits for 440 nm laser radiation (*see* Laser TLV®) because of the need for caution related to narrow-band spectral effects of lasers.

<u>Special Case For Small-Source Angles</u>: For a light source subtending an angle less than 0.011 radian, the above limits are relaxed. Determine the spectral irradiance (E_λ) weighted by the blue-light hazard function B(λ) :

$$E_B\,[\mathrm{W/cm^2}] = \sum_{305}^{700} E_\lambda \cdot B(\lambda) \cdot \Delta\lambda \tag{7}$$

For durations less than 100 s (1 min, 40 s) in a day, an acceptable exposure is present when:

$$E_B \leq \frac{0.01\,[\mathrm{J/cm^2}]}{t\,[\mathrm{s}]} \tag{8a}$$

Alternatively, for a source where the blue-light-weighted irradiance E_B exceeds 10^{-4} W/cm^2, the maximum acceptable exposure duration, t_{max}, in seconds is:

TLV®–PA

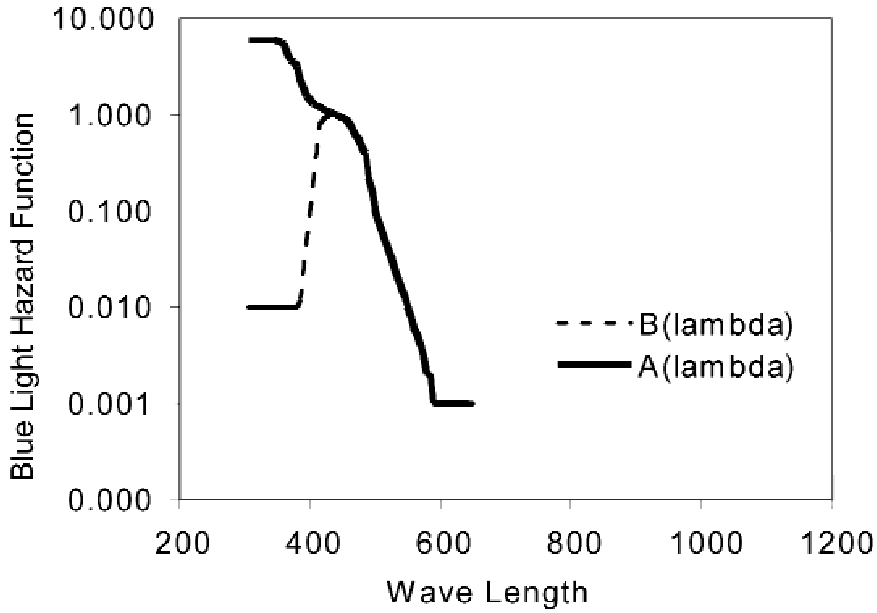

FIGURE 3. Blue light (retinal photochemical) hazard function for normal eyes [B(λ)] and the aphakic hazard function [A(λ)].

$$t_{max}\,[s] = \frac{0.01\,[J/cm^2]}{E_B} \tag{8b}$$

For viewing durations greater than 10^2 s (1 min, 40 s) in a day, an acceptable exposure is present when:

$$E_B \leq 10^{-4}\,[W/cm^2] \tag{8c}$$

<u>Special Case</u>: To protect the worker having a lens removed (cataract surgery) against retinal photochemical injury from chronic exposure: Unless an ultraviolet (UV)-absorbing intra-ocular lens has been surgically inserted into the eye, the Aphakic Hazard Function, A(λ), should be used for L_B and E_B, as shown in Equations 9a and 9b.

$$L_B\,[W/(cm^2\,sr)] = \sum_{305}^{700} L_\lambda \cdot A(\lambda) \cdot \Delta\lambda \tag{9a}$$

$$E_B\,[W/(cm^2\,sr)] = \sum_{305}^{700} E_\lambda \cdot A(\lambda) \cdot \Delta\lambda \tag{9b}$$

The value for L_B is used in Equation 6 and the value for E_B is used in Equation 8.

Section 3. *To protect against thermal injury to the cornea and lens from infrared (IR) radiation:* To avoid thermal injury of the cornea and possible delayed effects on the lens of the eye (cataractogenesis), the total infrared irradiance in hot environments is calculated as

$$E_{IR\text{–}only}\,[\mathrm{W/cm^2}] = \sum_{770}^{3000} E_\lambda \bullet \Delta\lambda \tag{10}$$

For exposure durations (t) less than 10^3 sec (17 min), an acceptable exposure is present when:

$$E_{IR\text{–}only}\,[\mathrm{W/cm^2}] \leq \frac{1.8}{t^{0.75}} \tag{11a}$$

For exposure durations greater than 10^3 sec (17 min), an acceptable exposure is present when:

$$E_{IR\text{–}only}\,[\mathrm{W/cm^2}] \leq 0.01 \tag{11b}$$

Section 4. *To protect against retinal thermal injury from near infrared (NIR) radiation:* For a near infrared source associated with an infrared heat lamp or any NIR source where a strong visual stimulus is absent (luminance less than 10^{-2} cd/cm^2), the total effective radiance (L_{NIR}) as viewed by the eye is the spectral radiance (L_λ) weighted by the thermal hazard function, R(λ).

$$L_{NIR}\,[\mathrm{W/(cm^2\,sr)}] = \sum_{770}^{1400} L_\lambda \bullet R(\lambda) \bullet \Delta\lambda \tag{12}$$

For exposures less than 810 s, an acceptable exposure is present when:

$$L_{NIR}\,[\mathrm{W/(cm^2\,sr)}] < \frac{3.2}{\alpha \bullet t^{1/4}} \tag{13a}♦$$

This limit is based upon a 7-mm pupil diameter (since the aversion response may not exist due to an absence of light) and a detector field-of-view of 0.011 rad.

For exposures greater than 810 s in a day, an acceptable exposure is present when:

$$L_{NIR}\,[\mathrm{W/(cm^2\,sr)}] \leq \frac{0.6}{\alpha} \tag{13b}♦$$

♦ Equations 3, 4, and 13 are empirical and are not, strictly speaking, dimensionally correct. To make the equations dimensionally correct, one would have to insert dimensional correction factors in the right-hand numerator in each equation.

TLV®–PA

‡ ULTRAVIOLET RADIATION

These TLVs® refer to ultraviolet (UV) radiation with wavelengths in air between 180 and 400 nm and 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, gas and vapor discharges, fluorescent and incandescent sources, and solar radiation, but they do not apply to UV lasers (*see* the TLVs® for Lasers). These values also do not apply to UV radiation exposure of photosensitive individuals or of individuals concomitantly exposed to photosensitizing agents (*see* Note 3). These values for the eye do not apply to aphakes (persons who have had the lens of the eye removed in cataract surgery [see Light and Near-Infrared Radiation TLVs®]). These values should be used as guides in the control of exposure to continuous sources for exposure durations equal to or greater than 0.1 second.

These values should be used as guides in the control of exposure to UV sources and should not be regarded as fine lines between safe and dangerous levels.

Threshold Limit Values

The TLVs® for occupational exposure to UV radiation incident upon the skin or the eye are as follows.

Ultraviolet Radiation (180 to 400 nm)

1. The UV radiant exposure incident upon the unprotected skin or eye(s) should not exceed the values in Table 1 in an 8-hour period. The values are specified in joules per square meter (J/m^2) and millijoules per square centimeter (mJ/cm^2) [Note: 1 mJ/cm^2 = 10 J/m^2].
2. The exposure time (t_{max}) in seconds to reach the TLV® for UV radiation incident upon the unprotected skin or eye may be computed by dividing 0.003 J/cm^2 by the effective irradiance (E_{eff}) in watts per square centimeter (W/cm^2).

$$t_{max} = \frac{0.003\ [J/cm^2]}{E_{eff}\ [W/cm^2]}$$

where: t_{max} = maximum exposure time in seconds
E_{eff} = effective irradiance relative to a monochromatic source at 270 nm in W/cm^2

Note: 1 W = 1 J/s

TABLE 1. Ultraviolet Radiation TLV® and Relative Spectral Effectiveness

Wavelength[A] (nm)	TLV® (J/m^2)[B]	TLV® (mJ/cm^2)[B]	Relative Spectral Effectiveness, $S(\lambda)$
180	2500	250	0.012
190	1600	160	0.019
200	1000	100	0.030
205	590	59	0.051
210	400	40	0.075
215	320	32	0.095
220	250	25	0.120
225	200	20	0.150
230	160	16	0.190
235	130	13	0.240
240	100	10	0.300
245	83	8.3	0.360
250	70	7.0	0.430
254[C]	60	6.0	0.500
255	58	5.8	0.520
260	46	4.6	0.650
265	37	3.7	0.810
270	30	3.0	1.000
275	31	3.1	0.960
280[C]	34	3.4	0.880
285	39	3.9	0.770
290	47	4.7	0.640
295	56	5.6	0.540
297[C]	65	6.5	0.460
300	100	10	0.300
303[C]	250	25	0.120
305	500	50	0.060
308	1200	120	0.026
310	2000	200	0.015
313[C]	5000	500	0.006
315	1.0×10^4	1.0×10^3	0.003
316	1.3×10^4	1.3×10^3	0.0024
317	1.5×10^4	1.5×10^3	0.0020
318	1.9×10^4	1.9×10^3	0.0016
319	2.5×10^4	2.5×10^3	0.0012
320	2.9×10^4	2.9×10^3	0.0010
322	4.5×10^4	4.5×10^3	0.00067
323	5.6×10^4	5.6×10^3	0.00054
325	6.0×10^4	6.0×10^3	0.00050
328	6.8×10^4	6.8×10^3	0.00044
330	7.3×10^4	7.3×10^3	0.00041
333	8.1×10^4	8.1×10^3	0.00037
335	8.8×10^4	8.8×10^3	0.00034
340	1.1×10^5	1.1×10^4	0.00028
345	1.3×10^5	1.3×10^4	0.00024
350	1.5×10^5	1.5×10^4	0.00020

TABLE 1 (con't.). Ultraviolet Radiation TLV® and Relative Spectral Effectiveness

Wavelength[A] (nm)	TLV® (J/m^2)[B]	TLV® (mJ/cm^2)[B]	Relative Spectral Effectiveness, $S(\lambda)$
355	1.9×10^5	1.9×10^4	0.00016
360	2.3×10^5	2.3×10^4	0.00013
365[C]	2.7×10^5	2.7×10^4	0.00011
370	3.2×10^5	3.2×10^4	0.000093
375	3.9×10^5	3.9×10^4	0.000077
380	4.7×10^5	4.7×10^4	0.000064
385	5.7×10^5	5.7×10^4	0.000053
390	6.8×10^5	6.8×10^4	0.000044
395	8.3×10^5	8.3×10^4	0.000036
400	1.0×10^6	1.0×10^5	0.000030

[A] Wavelengths chosen are representative; other values should be interpolated at intermediate wavelengths.
[B] $1\ mJ/cm^2 = 10\ J/m^2$
[C] Emission lines of a mercury discharge spectrum.

TLV®–PA

3. To determine E_{eff} for a broadband source weighted against the peak of the spectral effectiveness curve (270 nm), the following formula should be used:

$$E_{eff} = \sum_{180}^{400} E_\lambda S(\lambda)\Delta\lambda$$

where: E_{eff} = effective irradiance relative to a monochromatic source at 270 nm in W/cm^2
E_λ = spectral irradiance in $W/(cm^2 \bullet nm)$
$S(\lambda)$ = relative spectral effectiveness (unitless)
$\Delta\lambda$ = band width in nm

E_{eff} may also be measured directly with a UV radiometer having a built-in spectral response that mimics the relative spectral effectiveness values in Table 1. In either case, these values can be compared with the values in Table 2.

UV-A Spectral Region (315 to 400 nm)

In addition to the above TLV®, exposure of the unprotected eye(s) to UV-A should not exceed the following unweighted values:

1. A radiant exposure of 1.0 J/cm^2 for periods lasting less than 1000 seconds.
2. An irradiance of 1.0 mW/cm^2 for periods lasting 1000 seconds or more.

All preceding TLVs® for UV radiation apply to sources that subtend an angle less than 80 degrees at the detector. Sources that subtend a greater angle need to be measured only over an angle of 80 degrees.

TABLE 2. Exposure Durations for Given Actinic UV Radiation Effective Irradiances

Duration of Exposure Per Day	Effective Irradiance, E_{eff} ($\mu W/cm^2$)
8 hrs	0.1
4 hrs	0.2
2 hrs	0.4
1 hr	0.8
30 min	1.7
15 min	3.3
10 min	5
5 min	10
1 min	50
30 sec	100
10 sec	300
1 sec	3000
0.5 sec	6000
0.1 sec	30000

Notes:

1. The probability of developing skin cancer depends on a variety of factors such as skin pigmentation, a history of blistering sunburns, and the accumulated UV dose. It also depends on genetic susceptibility and factors such as skin and eye color. Individuals who have a familial history of melanoma, or numerous nevi over their body, for example, may be at higher risk of developing malignant melanoma.
2. Outdoor workers in latitudes within 40 degrees of the equator can be exposed to levels above the TLVs® in as little as 5 minutes around noontime during the summer.
3. Exposure to ultraviolet radiation concurrently with topical or systemic exposure to a variety of chemicals, including some prescription drugs, can result in skin erythema at sub-TLV® exposures. Hypersensitivity should be suspected if workers present skin reactions when exposed to sub-TLV® doses or when exposed to levels that did not cause a noticeable erythema in the same individual in the past. Among the hundreds of agents that can cause hypersensitivity to ultraviolet radiation are certain plants and chemicals such as some antibiotics (e.g., tetracycline and sulphathiazole), some antidepressants (e.g., imipramine and sinequan), as well as some diuretics, cosmetics, antipsychotic drugs, coal tar distillates, some dyes, or lime oil.
4. Ozone is produced in air by sources emitting UV radiation at wavelengths below 250 nm. Refer to the Chemical Substances TLV® for ozone.

NOTICE OF INTENDED CHANGE — † ULTRAVIOLET RADIATION

The reason for this NIC is to substantially revise text and notes, and to add Figures 1 and 2.

These TLVs® refer to incoherent ultraviolet (UV) radiation with wavelengths between 180 and 400 nm and 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. Some UV sources covered by this TLV® are welding and carbon arcs, gas and vapor discharges, fluorescent, incandescent and germicidal lamps, and solar radiation. Coherent UV radiation from lasers is covered in the TLV® for Lasers.

The TLV® values apply to continuous sources for exposure durations equal to or greater than 0.1 second. The sources may subtend an angle less than 80 degrees at the detector and for those sources that subtend a greater angle need to be measured over an angle of 80 degrees.

The values do not apply to UV radiation exposure of photosensitive individuals or of individuals concomitantly exposed to photosensitizing agents (*see* Note 3). The values for the eye do not apply to aphakes (persons who have had the lens of the eye removed in cataract surgery). In this case, see Light and Near-infrared Radiation TLVs®.

The TLVs® should be used as guides in the control of exposure to UV sources and should not be regarded as fine lines between safe and dangerous levels.

Threshold Limit Values

The TLVs® for occupational exposure to UV radiation incident upon the skin or the eye are as follows. The flow chart in Figure 1 provides a map of the UV TLV®.

Broadband UV Sources (180 to 400 nm) — Corneal Hazard

The first step in evaluating broadband UV sources is to determine the effective irradiance (E_{eff}). To determine E_{eff} for a broadband source weighted against the peak of the spectral effectiveness curve (270 nm), Equation 1 should be used.

$$E_{eff} = \sum_{180}^{400} E_{\lambda} \bullet S(\lambda) \bullet \Delta\lambda \tag{1}$$

where:
- E_{eff} = effective irradiance relative to a monochromatic source at 270 nm [W/cm^2]
- E_{λ} = spectral irradiance at a center wavelength [W/(cm^2 • nm)]
- $S(\lambda)$ = relative spectral effectiveness at the center wavelength [unitless]
- $\Delta\lambda$ = bandwidth around the center wavelength [nm]

More practically, E_{eff} can be measured directly with a UV radiometer having a built-in spectral response that mimics the relative spectral effectiveness values in Table 1 and Figure 2.

The daily exposure (t_{exp}) based on E_{eff} is dose limited to 0.003 J/cm^2. That is,

$$0.003[J/cm^2] \geq E_{eff}[W/cm^2] \bullet t_{exp}[s] \quad (2)$$

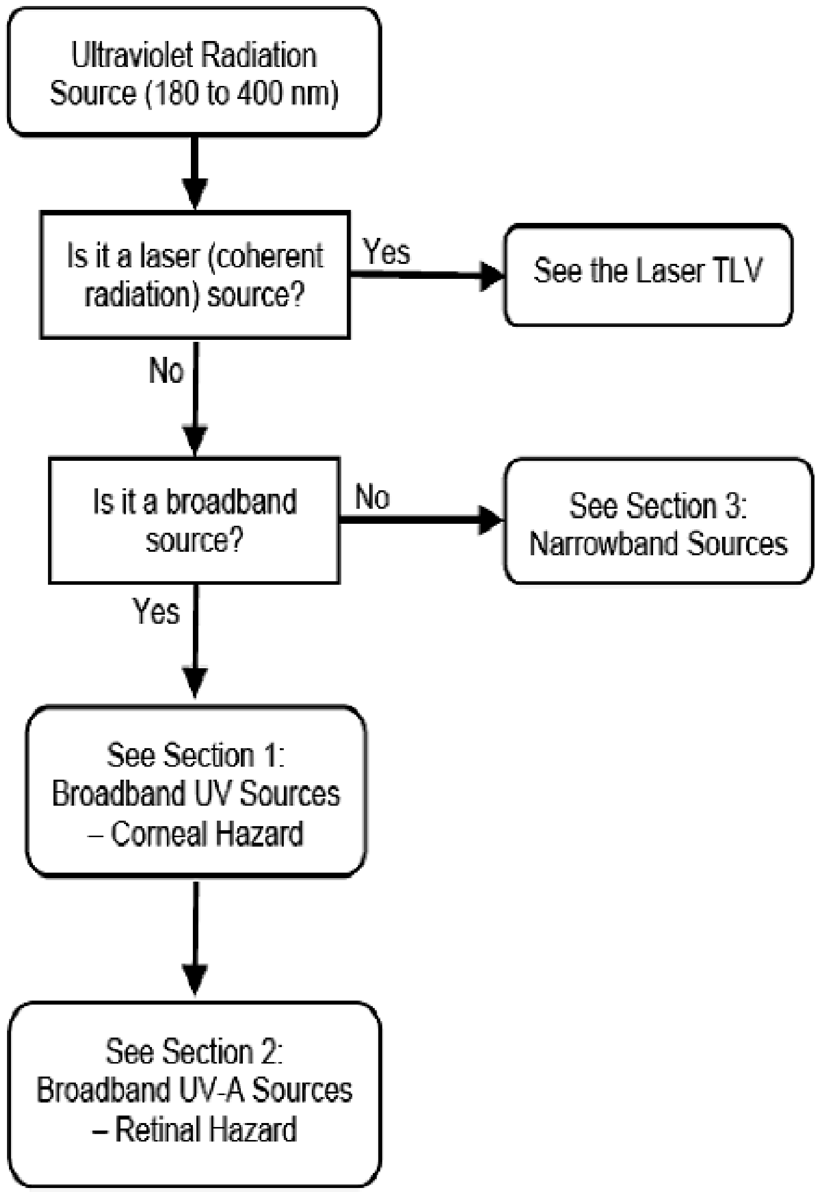

FIGURE 1. Flow chart for UV TLV®.

TLV®–PA

TABLE 1. Ultraviolet Radiation TLV® and Relative Spectral Effectiveness

Wavelength[A] (nm)	TLV® (J/m^2)[B]	TLV® (mJ/cm^2)[B]	Relative Spectral Effectiveness, S(λ)
180	2500	250	0.012
190	1600	160	0.019
200	1000	100	0.030
205	590	29	0.051
210	400	40	0.075
215	320	32	0.095
220	250	25	0.120
225	200	20	0.150
230	160	16	0.190
235	130	13	0.240
240	100	10	0.300
245	83	8.3	0.360
250	70	7.0	0.430
254[C]	60	6.0	0.500
255	58	5.8	0.520
260	46	4.6	0.650
265	37	3.7	0.810
270	30	3.0	1.00
275	31	3.1	0.960
280[C]	34	3.4	0.880
285	39	3.9	0.770
290	47	4.7	0.640
295	56	5.6	0.540
297[C]	65	6.5	0.460
300	100	10	0.300
303[C]	250	25	0.120
305	500	50	0.060
308	1200	120	0.026
310	2000	200	0.015
313[C]	5000	500	0.006
315	1.0×10^4	1.0×10^3	0.003
316	1.3×10^4	1.3×10^3	0.0024
317	1.5×10^4	1.5×10^3	0.0020
318	1.9×10^4	1.9×10^3	0.0016
319	2.5×10^4	2.5×10^3	0.0012
320	2.9×10^4	2.9×10^3	0.0010
322	4.5×10^4	4.5×10^3	0.00067
323	5.6×10^4	5.6×10^3	0.00054
325	6.0×10^4	6.0×10^3	0.00050
328	6.8×10^4	6.8×10^3	0.00044
330	7.3×10^4	7.3×10^3	0.00041
333	8.1×10^4	8.1×10^3	0.00037
335	8.8×10^4	8.8×10^3	0.00034
340	1.1×10^5	1.1×10^4	0.00028
345	1.3×10^5	1.3×10^4	0.00024
350	1.5×10^5	1.5×10^4	0.00020

TABLE 1 (con't.). Ultraviolet Radiation TLV® and Relative Spectral Effectiveness

Wavelength[A] (nm)	TLV® (J/m^2)[B]	TLV® (mJ/cm^2)[B]	Relative Spectral Effectiveness, S(λ)
355	1.9×10^5	1.9×10^4	0.00016
360	2.3×10^5	2.3×10^4	0.00013
365[C]	2.7×10^5	2.7×10^4	0.00011
370	3.2×10^5	3.2×10^4	0.000093
375	3.9×10^5	3.9×10^4	0.000077
380	4.7×10^5	4.7×10^4	0.000064
385	5.7×10^5	5.7×10^4	0.000053
390	6.8×10^5	6.8×10^4	0.000044
395	8.3×10^5	8.3×10^4	0.000036
400	1.0×10^6	1.0×10^5	0.000030

A Wavelengths chosen are representative; other values should be interpolated at intermediate wavelengths.
B 1 mJ/cm^2 = 10 J/m^2
C Emission lines of a mercury discharge spectrum.

TLV®–PA

Table 2 gives TLV® values for the effective irradiance for different daily exposure durations. In general, the maximum exposure time (t_{max}) [s] for a broadband UV source can be determined from Equation 3.

$$t_{\max}[s] = \frac{0.003\,[J/cm^2]}{E_{eff}[W/cm^2]} \quad (3)$$

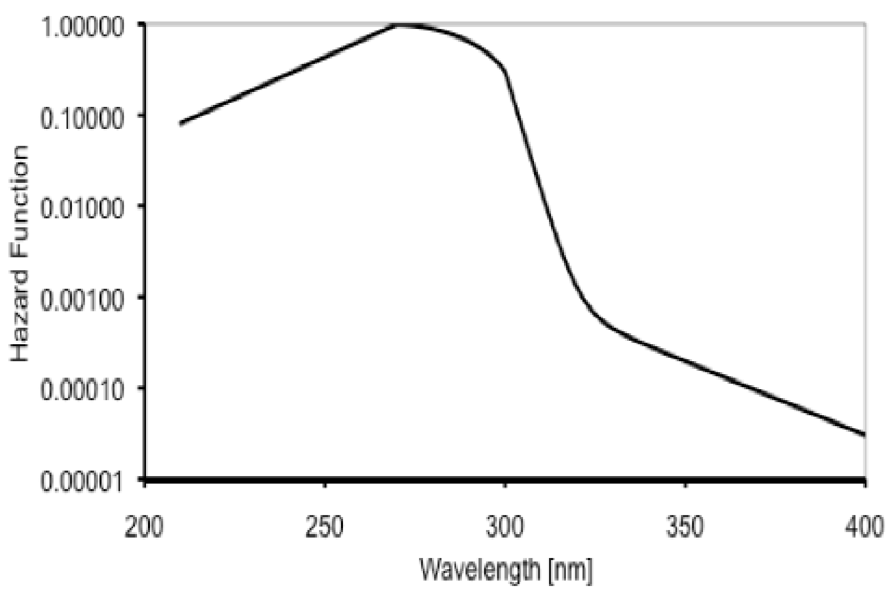

FIGURE 2. Hazard function (relative spectral effectiveness, S(λ) for UV.

TABLE 2. Exposure Durations for Given Actinic UV Radiation Effective Irradiances

Duration of Exposure Per Day	Effective Irradiance, E_{eff} (mW/cm^2)
8 hrs	0.0001
4 hrs	0.0002
2 hrs	0.0004
1 hr	0.0008
30 min	0.0017
15 min	0.0033
10 min	0.005
5 min	0.01
1 min	0.05
30 sec	0.1
10 sec	0.3
1 sec	3.
0.5 sec	6.
0.1 sec	30.

Broadband UV-A Sources (315 to 400 nm) — Lens and Retinal Hazard

The irradiance, $E_{UV\text{-}A}$ [mW/cm^2], can be measured with an unfiltered meter that is sensitive to UV-A radiation. For daily exposure periods (t_{exp}) less than 1000 s (17 min), the exposure is dose limited to 1000 mJ/cm^2 as described in Equation 4.

$$1000[mJ/cm^2] \geq E_{UV-A}[mW/cm^2] \bullet t_{exp}[s] \qquad (4)$$

For daily exposure periods greater than 1000 s (17 min), the exposure is rate limited to 1.0 mW/cm^2 as described in Equation 5.

$$1.0[mW/cm^2] \geq E_{UV-A}[mW/cm^2] \qquad (5)$$

Narrowband Sources

Narrowband sources are comprised of one wavelength or a narrow band of wavelengths (e.g., within 5–10 nm). Locate the center wavelength (λ) in Table 1, and find the TLV_λ as an eight-hour dose limit in J/m^2 or mJ/cm^2. The narrowband TLV® is protective for both corneal and retinal exposures.

The dose limit may be adjusted proportionately for work periods of longer or shorter duration. The TLV® dose limit of a daily exposure period (t_{exp}) for a narrowband source can be expressed as Equation 6 using the Spectral Sensitivity (S_λ) from Table 1 and unfiltered irradiance (E_λ) [W/m^2 or mW/cm^2].

$$30[J/m^2] \geq E_\lambda\,[W/m^2] \bullet S(\lambda) \bullet t_{exp}[s] \tag{6a}$$

$$3.0[mJ/cm^2] \geq E_\lambda\,[mW/cm^2] \bullet S(\lambda) \bullet t_{exp}[s] \tag{6b}$$

The maximum exposure time (t_{max}) [s] for a narrowband source can be determined from Equation 7 using the TLV_λ and the unfiltered irradiance (E_λ) [W/m^2 or mW/cm^2]. (Note: The energy and surface area units must match.)

$$t_{\max}[s] = \frac{TLV_\lambda}{E_\lambda} \tag{7}$$

Notes:

1. The probability of developing skin cancer depends on a variety of factors such as skin pigmentation, a history of blistering sunburns, and the accumulated UV dose. It also depends on genetic susceptibility and factors such as skin and eye color. Individuals who have a familial history of melanoma, or numerous nevi over their body, for example, may be at higher risk of developing malignant melanoma. The risks for developing melanoma and non-melanoma cancers may differ from each other and depend on the UV exposure history.
2. Outdoor workers in latitudes within 40 degrees of the equator can be exposed to levels above the TLVs® in as little as five minutes around noontime during the summer.
3. Exposure to ultraviolet radiation concurrently with topical or systemic exposure to a variety of chemicals, including some prescription drugs, can result in skin erythema at sub-TLV® exposures. Hypersensitivity should be suspected if workers present skin reactions when exposed to sub-TLV® doses or when exposed to levels that did not cause a noticeable erythema in the same individual in the past. Among the hundreds of agents that can cause hypersensitivity to UV radiation are certain plants and chemicals such as some antibiotics (e.g., tetracycline and sulphathiazole), some antidepressants (e.g., imipramine and sinequan), as well as some diuretics, cosmetics, antipsychotic drugs, coal tar distillates, some dyes, or lime oil.
4. Ozone is produced in air by sources emitting UV radiation at wavelengths below 250 nm. Refer to the latest version of the Chemical Substances TLV® for ozone.

‡ LASERS

These TLVs® are for exposure to laser radiation under conditions to which it is believed nearly all workers may be repeatedly exposed without adverse health effects. The TLVs® should be used as guides in the control of exposures and should not be regarded as fine lines between safe and dangerous levels. They are based on the best available information from experimental studies. In practice, hazards to the eye and skin can be controlled by application of control measures appropriate to the classification of the laser.

Classification of Lasers

Most lasers have a label affixed to them by the manufacturer that describes their hazard class. Normally, it is not necessary to determine laser irradiances or radiant exposures for comparison with the TLVs®. The potential for hazardous exposures can be minimized by the application of control measures that are appropriate to the hazard class of the laser. Control measures are applicable to all classes of lasers except for Class 1. Such measures, and other laser safety information, may be found in the ACGIH® publication, *A Guide for Control of Laser Hazards*, and the ANSI Z136 series published by the Laser Institute of America.

Limiting Apertures

For comparison with the TLVs® in this section, laser beam irradiance or radiant exposure is averaged over the limiting aperture appropriate to the spectral region and exposure duration. If the laser beam diameter is less than that of the limiting aperture, the effective laser beam irradiance or radiant exposure may be calculated by dividing the laser beam power or energy by the area of the limiting aperture. Limiting apertures are listed in Table 1.

TABLE 1. Limiting Apertures Applicable to Laser TLVs®

Spectral Region	Duration	Eye	Skin
180 nm–400 nm	1 ns to 0.25 s	1 mm	3.5 mm
180 nm–400 nm	0.25 s to 30 ks	3.5 mm	3.5 mm
400 nm–1400 nm	10^{-4} ns to 0.25 s	7 mm	3.5 mm
400 nm–1400 nm	0.25 s to 30 ks	7 mm	3.5 mm
1400 nm–0.1 mm	10^{-5} ns to 0.25 s	1 mm	3.5 mm
1400 nm–0.1 mm	0.25 s to 30 ks	3.5 mm	3.5 mm
0.1 mm–1.0 mm	10^{-5} ns to 30 ks	11 mm	11 mm

Repetitively Pulsed Exposures

Scanned, continuous-wave (CW) lasers or repetitively pulsed lasers can both produce repetitively pulsed exposure conditions. The TLV® for intrabeam viewing, which is applicable to wavelengths between 400 and 1400 nm and a single-pulse exposure (of pulse duration t), is modified in this instance by a correction factor determined by the number of pulses in the exposure. First, calculate the number of pulses (n) in an expected exposure situation; this is the pulse repetition frequency (PRF in Hz) multiplied by the duration of exposure. Normally, realistic exposures may range from 0.25 second (s) for a bright, visible source to 10 s for an infrared source. The corrected TLV® on a per-pulse basis is:

$$\text{TLV} = (n^{-1/4})\ (\text{TLV for Single-pulse}) \quad (1)$$

This approach applies only to thermal-injury conditions, i.e., all exposures at wavelengths > 700 nm and for many exposures at shorter wavelengths. For wavelengths ≤ 700 nm, the corrected TLV® from Equation 1 applies if the average irradiance does not exceed the TLV® for continuous exposure. The average irradiance (i.e., the total accumulated exposure for *nt* s) shall not exceed the radiant exposure given in Table 2 for exposure durations of 10 s to T_1.

It is recommended that the user of the TLVs® for laser radiation consult *A Guide for Control of Laser Hazards*, 4th Edition, 1990, published by ACGIH®, for additional information.

TABLE 2. TLVs® for Direct Ocular Exposures (Intrabeam "Point Source" Viewing) from a Laser Beam

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV®	
UVC	180 nm to 280 nm☆	10^{-9} to 3×10^4	3 mJ/cm²	not to exceed (NTE) $0.56\ t^{1/4}$ J/cm² for $t \leq 10$ s
UVB	280 nm to 302 nm	"	3 "	
	303 nm	"	4 "	
	304 nm	"	6 "	
	305 nm	"	10 "	
	306 nm	"	16 "	
	307 nm	"	25 "	
	308 nm	"	40 "	
	309 nm	"	63 "	
	310 nm	"	100 "	
	311 nm	"	160 "	
	312 nm	"	250 "	
	313 nm	"	400 "	
	314 nm	"	630 "	
UVA	315 nm to 400 nm	10^{-9} to 10	$0.56t^{1/4}$ J/cm²	
	" "	10 to 10^3	1.0 J/cm²	
	" "	10^3 to 3×10^4	1.0 mW/cm²	

TABLE 2 (con't.). TLVs® for Direct Ocular Exposures (Intrabeam "Point Source" Viewing) from a Laser Beam

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV®	
Light	400 to 700 nm	10^{-13} to 10^{-11}	15 nJ/cm^2	
	400 to 700 nm	10^{-11} to 10^{-9}	2.7 $t^{0.75}$ J/cm^2	
	400 to 700 nm	10^{-9} to 18×10^{-6}	5.0×10^{-1} µJ/cm^2	
	400 to 700 nm	18×10^{-6} to 10	1.8 $t^{0.75}$ mJ/cm^2	
	400 to 450 nm	10 to 100	10 mJ/cm^2	
	450 to 500 nm	10 to T_1	1 mW/cm^2	
	450 to 500 nm	T_1 to 100	10 C_B mJ/cm^2	
	400 to 500 nm	100 to 3×10^4	0.1 C_B mW/cm^2	
	500 to 700 nm	10 to 3×10^4	1.0 mW/cm^2	
IRA	700 to 1050 nm	10^{-13} to 10^{-11}	15 C_A nJ/cm^2	
	700 to 1050 nm	10^{-11} to 10^{-9}	2.7 C_A $t^{0.75}$ J/cm^2	
	700 to 1050 nm	10^{-9} to 18×10^{-6}	0.5 C_A µJ/cm^2	
	700 to 1050 nm	18×10^{-6} to 10	1.8 C_A $t^{0.75}$ mJ/cm^2	
	700 to 1050 nm	10 to 3×10^4	C_A mW/cm^2	
	1050 to 1400 nm	10^{-13} to 10^{-11}	1.5 $C_C \times 10^{-1}$ µJ/cm^2	
	1050 to 1400 nm	10^{-11} to 10^{-9}	27.0 C_C $t^{0.75}$ J/cm^2	
	1050 to 1400 nm	10^{-9} to 50×10^{-6}	5.0 C_C µJ/cm^2	
	1050 to 1400 nm	50×10^{-6} to 10	9.0 C_C $t^{0.75}$ mJ/cm^2	NTE 1.0 J/cm^2
	1050 to 1400 nm	10 to 3×10^4	5.0 C_C mW/cm^2	NTE 100 mW/cm^2

TABLE 2 (con't.). TLVs® for Direct Ocular Exposures (Intrabeam "Point Source" Viewing) from a Laser Beam

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV®
IRB	1.401 to 1.5 µm	10^{-14} to 10^{-3}	0.1 J/cm^2
& IRC	1.401 to 1.5 µm	10^{-3} to 10	0.56 $t^{1/4}$ J/cm^2
	1.501 to 1.8 µm	10^{-14} to 10	1.0 J/cm^2
	1.801 to 2.6 µm	10^{-14} to 10^{-3}	0.1 J/cm^2
	1.801 to 2.6 µm	10^{-3} to 10	0.56 $t^{1/4}$ J/cm^2
	2.601 to 10^3 µm	10^{-14} to 10^{-7}	10 mJ/cm^2
	2.601 to 10^3 µm	10^{-7} to 10	0.56 $t^{1/4}$ J/cm^2
	1.400 to 10^3 µm	10 to 3×10^4	100 mW/cm^2

*Ozone (O_3) is produced in air by sources emitting ultraviolet (UV) radiation at wavelengths below 250 nm. Refer to Chemical Substances TLV® for ozone.

Notes for Table 2

C_A = Fig. 2; $C_B = 1$ for $\lambda = 400$ to ≤ 450 nm; $C_B = 10^{0.02(\lambda - 450)}$ for $\lambda = 450$ to 600 nm; $C_C = 1.0$ from 700 to 1150 nm; $C_C = 10^{[0.0181(\lambda - 1150)]}$ for wavelengths greater than 1150 nm and less than 1200 nm; $C_C = 8.0$ from 1200 to 1300 nm; $C_C = 8 + 10^{0.04(\lambda - 1300)}$ from 1300 nm to 1400 nm.

$T_1 = 10$ s for $\lambda = 400$ to 450 nm; $T_1 = 10 \times 10^{[0.02(\lambda - 550)]}$ for $\lambda = 450$ to 500 nm; and $T_1 = 10$ s for $\lambda = 500$ to 700

For intermediate or large sources (e.g., laser diode arrays) at wavelengths between 400 nm and 1400 nm, the intrabeam viewing TLVs® can be increased by correction factor C_E (use Table 3) provided that the angular subtense α of the source (measured at the viewer's eye) is greater than α_{min}. C_E depends on α as follows:

Angular Subtense	Source Size Designation	Correction Factor C_E
$\alpha \leq \alpha_{min}$	Small	$C_E = 1$
$\alpha_{min} < \alpha \leq \alpha_{max}$	Intermediate	$C_E = \alpha/\alpha_{min}$
$\alpha > \alpha_{max}$	Large	$C_E = \alpha_{max}/\alpha_{min} = 3.33$ for $t \leq 0.625$ ms; $= 133.33\ t^{1/2}$ for 0.625 ms $< t <$ 0.25 s $= 66.7$ for $t \geq 0.25$ s

The angle referred to as α_{max} corresponds to the point where the TLVs® may be expressed as a constant radiance and the last equation can be rewritten in terms of radiance L.

$L_{TLV} = (3.81 \times 10^5) \times (TLV_{pt\ source})$ J/(cm^2 sr) for $t < 0.625$ µs for $400 < \lambda < 700$ nm

$L_{TLV} = 7.6\ t^{1/4}$ J/(cm^2 sr) for 0.625 ms $< t <$ 0.25 s for $400 < \lambda < 700$ nm

$L_{TLV} = 4.8$ W/(cm^2 sr) for $t > 100$ s for $400 < \lambda < 700$ nm

Figure 5 illustrates these TLVs® for large sources expressed in terms of radiance.

The measurement aperture should be placed at a distance of 100 mm or greater from the source. For large area irradiation, the reduced TLV® for skin exposure applies as noted in the footnote to "IRB & C," Table 4.

TABLE 3. TLVs® for Extended Source Laser Viewing Conditions

Spectral Region	Wavelength	Exposure, (t) seconds	TLV®
Light	400 to 700 nm	10^{-13} to 10^{-11}	$1.5\ C_E\ 10^{-8}$ J/cm^2
	400 to 700 nm	10^{-11} to 10^{-9}	$2.7\ C_E\ t^{0.75}$ J/cm^2
	400 to 700 nm	10^{-9} to 18×10^{-6}	$5.0\ C_E \times 10^{-7}$ J/cm^2
	400 to 700 nm	18×10^{-6} to 0.7	$1.8\ C_E\ t^{0.75} \times 10^{-3}$ J/cm^2
	Dual Limits for 400 to 600 nm visible laser exposure for t > 0.7 s		
	Photochemical		
	For $\alpha \leq 11$ mrad, the MPE is expressed as irradiance and radiant exposure*		
	400 to 600 nm	0.7 to 100	$C_B \times 10^{-2}$ J/cm^2
	400 to 600 nm	100 to 3×10^4	$C_B \times 10^{-4}$ W/cm^2
	For $\alpha > 11$ mrad, the MPE is expressed as radiance and integrated radiance*		
	400 to 600 nm	0.7 to 1×10^4	$100\ C_B$ J/(cm^2 sr)
	400 to 600 nm	1×10^4 to 3×10^4	$C_B \times 10^{-2}$ W/(cm^2 sr)
		and	
	Thermal		
	400 to 700 nm	0.7 to T_2	$1.8\ C_E\ t^{0.75} \times 10^{-3}$ J/cm^2
	400 to 700 nm	T_2 to 3×10^4	$1.8\ C_E\ T_2^{-0.25} \times 10^{-3}$ W/cm^2

TABLE 3 (con't.). TLVs® for Extended Source Laser Viewing Conditions

Spectral Region	Wavelength	Exposure, (t) seconds	TLV®	
IRA	700 to 1050 nm	10^{-13} to 10^{-11}	$1.5\ C_A\ C_E \times 10^{-8}$ J/cm^2	
	700 to 1050 nm	10^{-11} to 10^{-9}	$2.7\ C_A\ C_E\ t^{0.75}$ J/cm^2	
	700 to 1050 nm	10^{-9} to 18×10^{-6}	$5.0\ C_A\ C_E \times 10^{-7}$ J/cm^2	
	700 to 1050 nm	18×10^{-6} to T_2	$1.8\ C_A\ C_E\ t^{0.75} \times 10^{-3}$ J/cm^2	
	700 to 1050 nm	T_2 to 3×10^4	$1.8\ C_A\ C_E\ T_2^{-0.25} \times 10^{-3}$ W/cm^2	
	1050 to 1400 nm	10^{-13} to 10^{-11}	$1.5\ C_C\ C_E \times 10^{-7}$ J/cm^2	
	1050 to 1400 nm	10^{-11} to 10^{-9}	$27.0\ C_C\ C_E\ t^{0.75}$ J/cm^2	
	1050 to 1400 nm	10^{-9} to 50×10^{-6}	$5.0\ C_C\ C_E \times 10^{-6}$ J/cm^2	
	1050 to 1400 nm	50×10^{-6} to T_2	$9.0\ C_C\ C_E\ t^{0.75} \times 10^{-3}$ J/cm^2	NTE 1.0 J/cm^2
	1050 to 1400 nm	T_2 to 3×10^4	$9.0\ C_C\ C_E\ T_2^{-0.25} \times 10^{-3}$ W/cm^2	NTE 1.0 J/cm^2

* For sources subtending an angle greater than 11 mrad, the limit may also be expressed as an integrated radiance L_p = 100 C_B J/(cm^2 sr) for 0.7 s $\leq t < 10^4$ s and $L_e = C_B \times 10^{-2}$ W/(cm^2 sr) for $t \geq 10^4$ s as measured through a limiting cone angle γ.

TABLE 3 (con't.). TLVs® for Extended Source Laser Viewing Conditions

These correspond to values of J/cm^2 for $10\ s \leq t < 100\ s$ and W/cm^2 for $t \geq 100\ s$ as measured through a limiting cone angle γ.

$\gamma = 11$ mrad for $0.7\ s \leq t < 100\ s$
$\gamma = 1.1 \times t^{0.5}$ mrad for $100\ s \leq t < 10^4\ s$
$\gamma = 110$ mrad for $10^4\ s \leq t < 3 \times 10^4\ s$

$T_2 = 10 \times 10^{(\alpha - 1.5)/98.5}$ for α expressed in mrad for $\lambda = 400$ to 1400 nm.

For exposure duration "t", the angle α_{max} is defined as:

$\alpha_{max} = 5$ mrad for $t \leq$ to 0.625 ms
$\alpha_{max} = 200\ t^{0.5}$ mrad for $0.625\ ms < t < 0.25\ s$, and
$\alpha_{max} = 100$ mrad for $t \geq 0.25\ s$
$\alpha_{min} = 1.5$ mrad

TABLE 4. TLVs® for Skin Exposure from a Laser Beam

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV®
UVA[A]	180 nm to 400 nm	10^{-9} to 10^{4}	Same as Table 2
Light & IRA	400 nm to 1400 nm	10^{-9} to 10^{-7}	$2\ C_A \times 10^{-2}$ J/cm^2
	" "	10^{-7} to 10	$1.1\ C_A\ \sqrt[4]{t}$ J/cm^2
	" "	10 to 3×10^{4}	$0.2\ C_A$ W/cm^2
IRB & C[B]	1.401 to 10^{3} µm	10^{-14} to 3×10^{4}	Same as Table 2

[A] Ozone (O_3) is produced in air by sources emitting ultraviolet (UV) radiation at wavelengths below 250 nm. Refer to Chemical Substances TLV® for ozone.

C_A = 1.0 for λ = 400 – 700 nm; see Figure 2 for λ = 700 to 1400 nm

[B] At wavelengths greater than 1400 nm, for beam cross-sectional areas exceeding 100 cm^2, the TLV® for exposure durations exceeding 10 seconds is:

$$TLV = (10{,}000/A_s)\ mW/cm^2$$

where A_s is the irradiated skin area for 100 to 1000 cm^2, and the TLV® is 10 mW/cm^2 for irradiated skin areas exceeding 1000 cm^2 and is 100 mW/cm^2 for irradiated skin areas less than 100 cm^2.

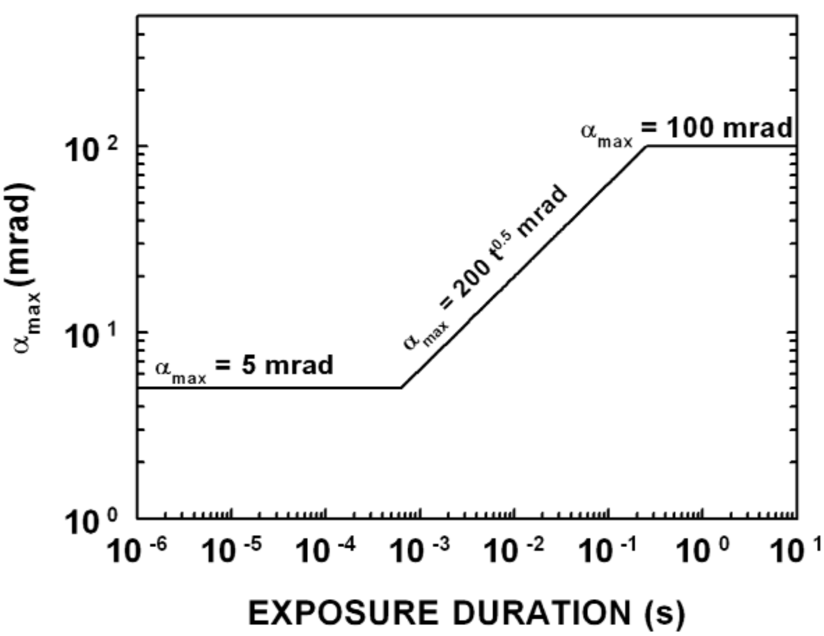

FIGURE 1. Variation of α_{max} with exposure duration.

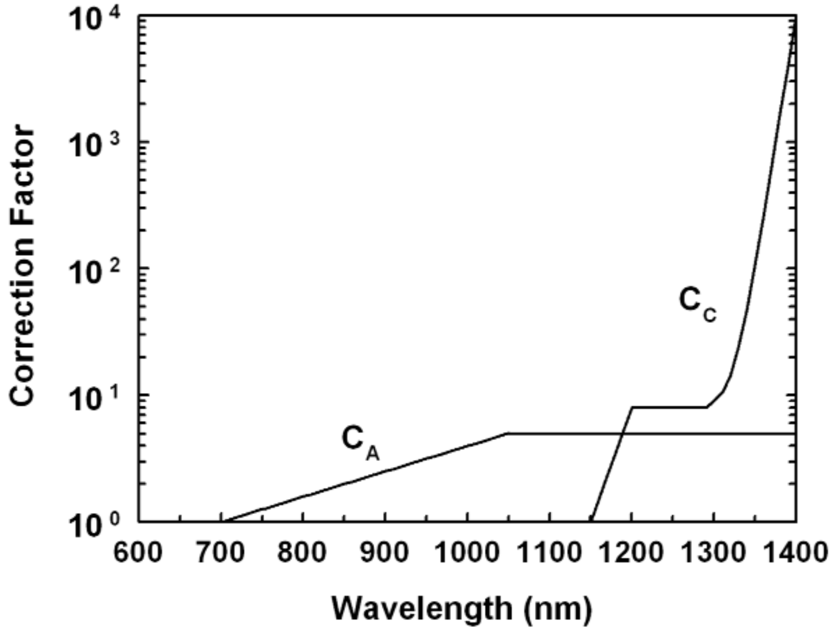

FIGURE 2. TLV® correction factor for λ = 700–1400 nm*
(*For λ = 700–1049 nm, $C_A = 10^{[0.002(\lambda - 700)]}$; for λ = 1050–1400 nm, C_A = 5. For $\lambda \leq 1150$, C_C = 1; for λ = 1150–1200, $C_C = 10^{0.018(\lambda - 1150)}$; for λ = 1200–1300, C_C = 8; and for λ = 1200–1300, $C_C = 8 + 10^{0.04(\lambda - 1300)}$).

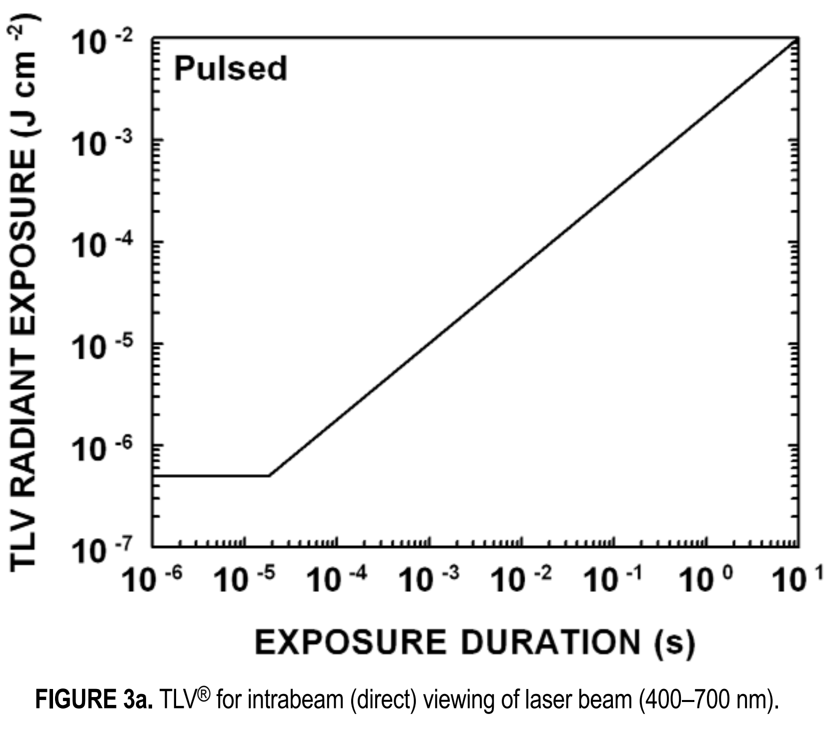

FIGURE 3a. TLV® for intrabeam (direct) viewing of laser beam (400–700 nm).

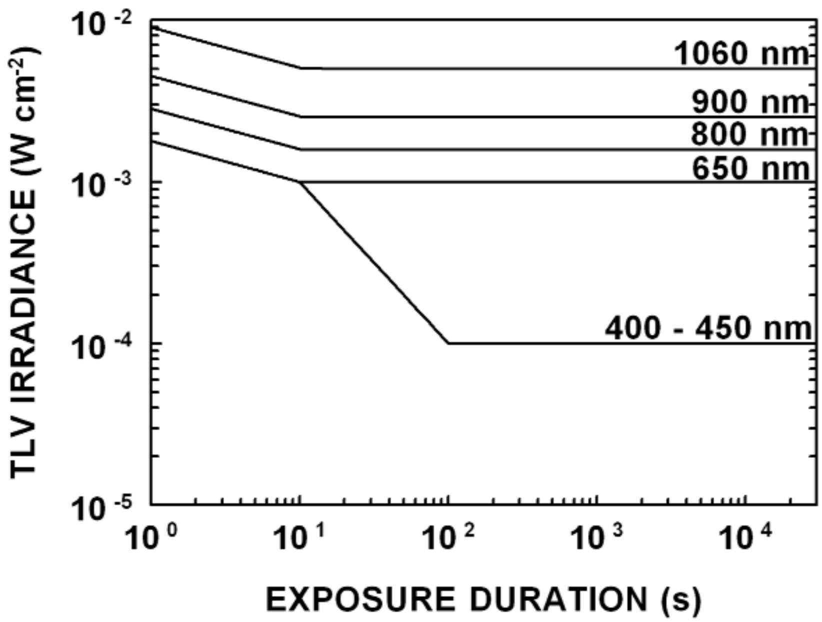

FIGURE 3b. TLV® for intrabeam (direct) viewing of CW laser beam (400–1400 nm).

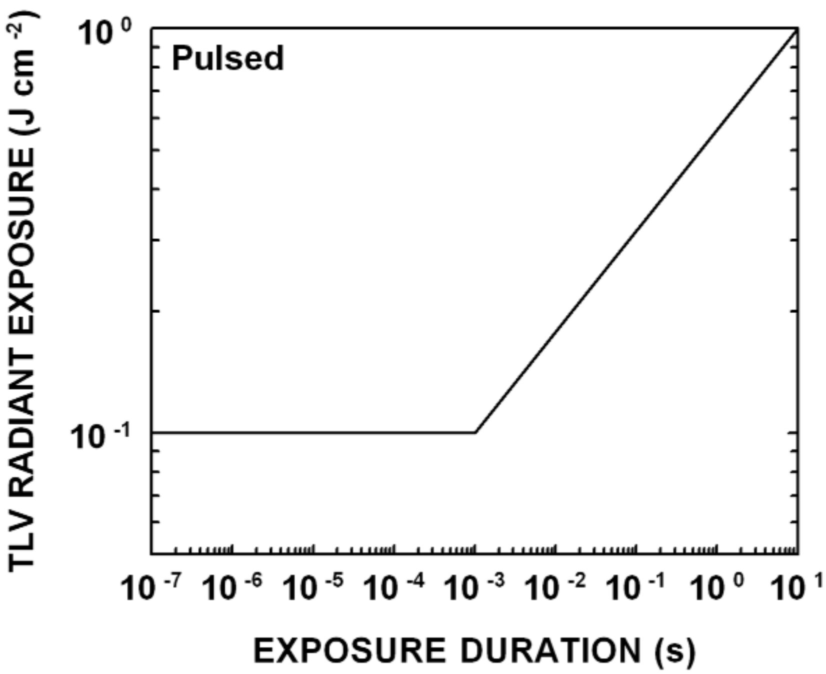

FIGURE 4a. TLV® for laser exposure of skin and eyes for far-infrared radiation (wavelengths greater than 1.4 μm).

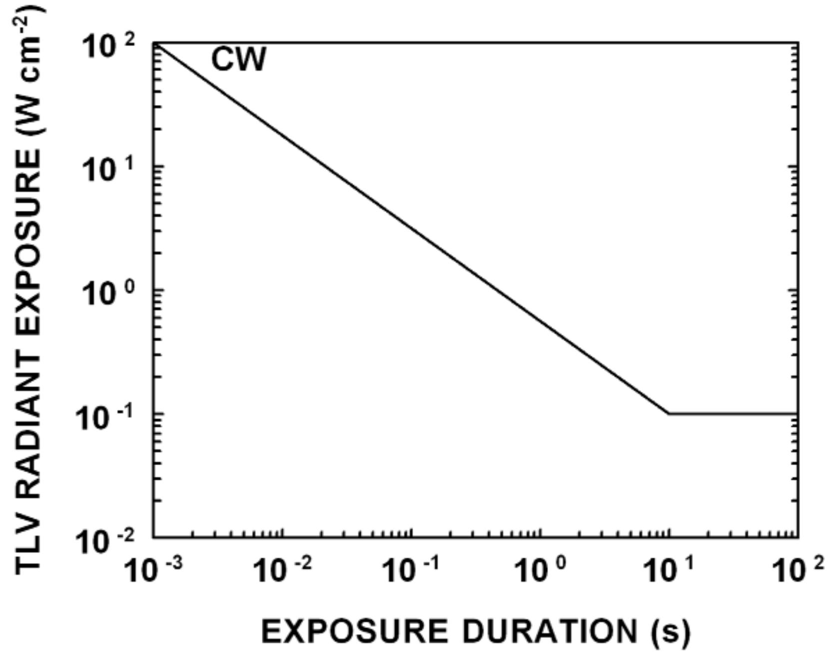

FIGURE 4b. TLV® for CW laser exposure of skin and eyes for far-infrared radiation (wavelengths greater than 1.4 μm).

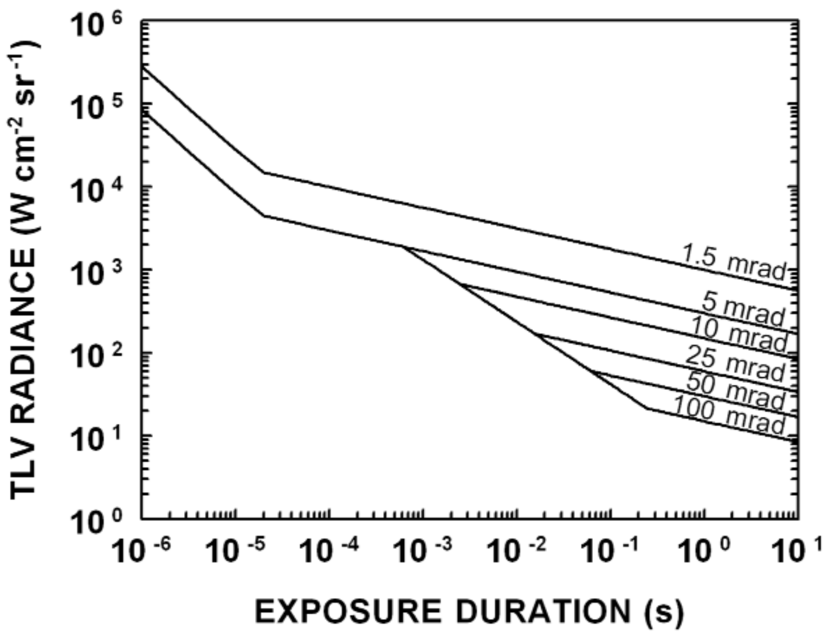

FIGURE 5. TLVs® in terms of radiance for exposures to extended-source lasers in the wavelength range of 400 to 700 nm.

NOTICE OF INTENDED CHANGE — † LASERS

The reason for this NIC is to revise the TLV® for correction factor C_c for wavelengths between 1200–1400 nm.

These TLVs® are for exposure to laser radiation under conditions to which it is believed nearly all workers may be repeatedly exposed without adverse health effects. The TLVs® should be used as guides in the control of exposures and should not be regarded as fine lines between safe and dangerous levels. They are based on the best available information from experimental studies. In practice, hazards to the eye and skin can be controlled by application of control measures appropriate to the classification of the laser.

Classification of Lasers

Most lasers have a label affixed to them by the manufacturer that describes their hazard class. Normally, it is not necessary to determine laser irradiances or radiant exposures for comparison with the TLVs®. The potential for hazardous exposures can be minimized by the application of control measures that are appropriate to the hazard class of the laser. Control measures are applicable to all classes of lasers except for Class 1. Such measures, and other laser safety information, may be found in the ACGIH® publication, *A Guide for Control of Laser Hazards*, and the ANSI Z136 series published by the Laser Institute of America.

Limiting Apertures

For comparison with the TLVs® in this section, laser beam irradiance or radiant exposure is averaged over the limiting aperture appropriate to the spectral region and exposure duration. If the laser beam diameter is less than that of the limiting aperture, the effective laser beam irradiance or radiant exposure may be calculated by dividing the laser beam power or energy by the area of the limiting aperture. Limiting apertures are listed in Table 1.

Source Size and Correction Factor C_E

The following considerations apply only at wavelengths in the retinal hazard region, 400–1400 nanometers (nm). Normally, a laser is a small source, which approximates a "point" source and subtends an angle less than α_{min}, which is 1.5 mrad for all values of t. However, any source which subtends an angle, α, greater than α_{min}, and is measured from the viewer's eye, is treated as an "intermediate source" ($\alpha_{min} < \alpha \leq \alpha_{max}$) or a "large, extended source" ($\alpha > \alpha_{max}$). For exposure duration "t", the angle α_{max} is defined as:

α_{max} = 5 mrad for t $\leq$ to 0.625 ms
α_{max} = 200 • $t^{0.5}$ mrad for 0.625 ms < t < 0.5 s, and
α_{max} = 100 mrad for t $\geq$ 0.25 s
α_{min} = 1.5 mrad

Figure 1 illustrates the time dependence of α_{max}. If the source is oblong, alpha is determined from the arithmetic average of the longest and shortest viewable dimensions.

For intermediate and large sources, the TLVs® in Table 2 are modified by a correction factor C_E, as detailed in the Notes for Table 2.

Correction Factors A, B, C (C_A, C_B, C_C)

The TLVs® for ocular exposures in Table 2 are to be used as given for all wavelength ranges. The TLVs® for wavelengths between 700 and 1049 nm are to be increased by the factor C_A (to account for reduced absorption of melanin) as given in Figure 2. For certain exposure times at wavelengths between 400 and 600 nm, a correction factor C_B (to account for reduced photochemical sensitivity for retinal injury) is applied. The correction factor C_C is applied from 1150 to 1400 nm to account for pre-retinal absorption of the ocular media.

The TLVs® for skin exposure are given in Table 4. The TLVs® are to be increased by a factor C_A, as shown in Figure 2, for wavelengths between 700 nm and 1400 nm. To aid in the determination for exposure durations requiring calculations of fractional powers, Figures 3a, 3b, 4a, and 4b may be used.

Repetitively Pulsed Exposures

Scanned, continuous-wave (CW) lasers or repetitively pulsed lasers can both produce repetitively pulsed exposure conditions. The TLV® for intrabeam viewing, which is applicable to wavelengths between 400 and 1400 nm and a single-pulse exposure (of pulse duration t), is modified in this instance by a correction factor determined by the number of pulses in the exposure. First, calculate the number of pulses (n) in an expected exposure situation; this is the pulse repetition frequency (PRF in Hz) multiplied by the duration of exposure. Normally, realistic exposures may range from 0.25 second (s) for a bright, visible source to 10 s for an infrared source. The corrected TLV® on a per-pulse basis is:

$$\text{TLV} = (n^{-1/4})(\text{TLV for Single-pulse}) \qquad \textbf{(1)}$$

This approach applies only to thermal-injury conditions, i.e., all exposures at wavelengths > 700 nm and for many exposures at shorter wavelengths. For wavelengths $\leq$ 700 nm, the corrected TLV® from Equation 1 applies if the average irradiance does not exceed the TLV® for continuous exposure. The average irradiance (i.e., the total accumulated exposure for *nt* s) shall not exceed the radiant exposure given in Table 2 for exposure durations of 10 s to T_1.

It is recommended that the user of the TLVs® for laser radiation consult *A Guide for Control of Laser Hazards*, 4th Edition, 1990, published by ACGIH®, for additional information.

TABLE 1. Limiting Apertures Applicable to Laser TLVs®

Spectral Region	Duration	Eye	Skin
180 nm–400 nm	1 ns to 0.25 s	1 mm	3.5 mm
180 nm–400 nm	0.25 s to 30 ks	3.5 mm	3.5 mm
400 nm–1400 nm	10^{-4} ns to 0.25 s	7 mm	3.5 mm
400 nm–1400 nm	0.25 s to 30 ks	7 mm	3.5 mm
1400 nm–0.1 mm	10^{-5} ns to 0.25 s	1 mm	3.5 mm
1400 nm–0.1 mm	0.25 s to 30 ks	3.5 mm	3.5 mm
0.1 mm–1.0 mm	10^{-5} ns to 30 ks	11 mm	11 mm

TLV®–PA

TABLE 2. TLVs® for Direct Ocular Exposures (Intrabeam "Point Source" Viewing) from a Laser Beam

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV®
UVC	180 nm to 280 nm*	10^{-9} to 3×10^4	3 mJ/cm^2
UVB	280 nm to 302 nm	"	3 mJ/cm^2
	303 nm	"	4 mJ/cm^2
	304 nm	"	6 mJ/cm^2
	305 nm	"	10 mJ/cm^2
	306 nm	"	16 mJ/cm^2
	307 nm	"	25 mJ/cm^2
	308 nm	"	40 mJ/cm^2 .
	309 nm	"	63 mJ/cm^2
	310 nm	"	100 mJ/cm^2
	311 nm	"	160 mJ/cm^2
	312 nm	"	250 mJ/cm^2
	313 nm	"	400 mJ/cm^2
	314 nm	"	630 mJ/cm^2
UVA	315 nm to 400 nm	10^{-9} to 10	$0.56\ t^{1/4}$ J/cm^2
	315 nm to 400 nm	10 to 10^3	1.0 J/cm^2
	315 nm to 400 nm	10^3 to 3×10^4	1.0 mW/cm^2

Not to exceed (NTE) $0.56\ t^{1/4}$ J/cm^2 for $t \leq 10$ s

TABLE 2 (con't.). TLVs® for Direct Ocular Exposures (Intrabeam "Point Source" Viewing) from a Laser Beam

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV®	
Light	400 to 700 nm	10^{-13} to 10^{-11}	15 nJ/cm^2	
	400 to 700 nm	10^{-11} to 10^{-9}	2.7 $t^{0.75}$ J/cm^2	
	400 to 700 nm	10^{-9} to 18×10^{-6}	5.0×10^{-1} μJ/cm^2	
	400 to 700 nm	18×10^{-6} to 10	1.8 $t^{0.75}$ mJ/cm^2	
	400 to 450 nm	10 to 100	10 mJ/cm^2	
	450 to 500 nm	10 to T_1	1 mW/cm^2	
	450 to 500 nm	T_1 to 100	10 C_B mJ/cm^2	
	400 to 500 nm	100 to 3×10^4	0.1 C_B mW/cm^2	
	500 to 700 nm	10 to 3×10^4	1.0 mW/cm^2	
IRA	700 to 1050 nm	10^{-13} to 10^{-11}	15 C_A nJ/cm^2	
	700 to 1050 nm	10^{-11} to 10^{-9}	2.7 C_A $t^{0.75}$ J/cm^2	
	700 to 1050 nm	10^{-9} to 18×10^{-6}	0.5 C_A μJ/cm^2	
	700 to 1050 nm	18×10^{-6} to 10	1.8 C_A $t^{0.75}$ mJ/cm^2	
	700 to 1050 nm	10 to 3×10^4	C_A mW/cm^2	
	1050 to 1400 nm	10^{-13} to 10^{-11}	1.5 $C_C \times 10^{-1}$ μJ/cm^2	
	1050 to 1400 nm	10^{-11} to 10^{-9}	27.0 C_C $t^{0.75}$ J/cm^2	
	1050 to 1400 nm	10^{-9} to 50×10^{-6}	5.0 C_C μJ/cm^2	
	1050 to 1400 nm	50×10^{-6} to 10	9.0 C_C $t^{0.75}$ mJ/cm^2	NTE 1.0 J/cm^2
	1050 to 1400 nm	10 to 3×10^4	5.0 C_C mW/cm^2	NTE 100 mW/cm^2

TABLE 2 (con't.). TLVs® for Direct Ocular Exposures (Intrabeam "Point Source" Viewing) from a Laser Beam

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV®
IRB	1.401 to 1.5 µm	10^{-14} to 10^{-3}	0.1 J/cm^2
& IRC	1.401 to 1.5 µm	10^{-3} to 10	0.56 $t^{1/4}$ J/cm^2
	1.501 to 1.8 µm	10^{-14} to 10	1.0 J/cm^2
	1.801 to 2.6 µm	10^{-14} to 10^{-3}	0.1 J/cm^2
	1.801 to 2.6 µm	10^{-3} to 10	0.56 $t^{1/4}$ J/cm^2
	2.601 to 10^3 µm	10^{-14} to 10^{-7}	10 mJ/cm^2
	2.601 to 10^3 µm	10^{-7} to 10	0.56 $t^{1/4}$ J/cm^2
	1.400 to 10^3 µm	10 to 3×10^4	100 mW/cm^2

*Ozone (O_3) is produced in air by sources emitting ultraviolet (UV) radiation at wavelengths below 250 nm. Refer to Chemical Substances TLV® for ozone.

Notes for Table 2

C_A = Fig. 2; $C_B = 1$ for $\lambda = 400$ to ≤ 450 nm; $C_B = 10^{0.02(\lambda - 450)}$ for $\lambda = 450$ to 600 nm; $C_C = 1.0$ for wavelengths less than or equal to 1150 nm; $C_C = 10^{[0.0181\,(\lambda - 1150)]}$ for wavelengths greater than 1150 nm and less than 1200 nm; $C_C = 8.0$ from 1200 to 1250 nm; $C_C = 7 + 10^{0.04\,(\lambda - 1250)}$ from 1250 nm to 1400 nm.

$T_1 = 10$ s for $\lambda = 400$ to 450 nm; $T_1 = 10 \times 10^{[0.02\,(\lambda - 550)]}$ for $\lambda = 450$ to 500 nm; and $T_1 = 10$ s for $\lambda = 500$ to 700.

For intermediate or large sources (e.g., laser diode arrays) at wavelengths between 400 nm and 1400 nm, the intrabeam viewing TLVs® can be increased by correction factor C_E (use Table 3) provided that the angular subtense α of the source (measured at the viewer's eye) is greater than α_{min}. C_E depends on α as follows:

Angular Subtense	Source Size Designation	Correction Factor C_E
$\alpha \leq \alpha_{min}$	Small	$C_E = 1$
$\alpha_{min} < \alpha \leq \alpha_{max}$	Intermediate	$C_E = \alpha/\alpha_{min}$
$\alpha > \alpha_{max}$	Large	$C_E = \alpha_{max}/\alpha_{min} = 3.33$ for $t \leq 0.625$ ms; $= 133.33\, t^{1/2}$ for 0.625 ms $< t < 0.25$ s $= 66.7$ for $t \geq 0.25$ s

The angle referred to as α_{max} corresponds to the point where the TLVs® may be expressed as a constant radiance and the last equation can be rewritten in terms of radiance L.

$$L_{TLV} = (3.81 \times 10^5) \times (TLV_{pt\ source})\ \mathrm{J/(cm^2\ sr)} \text{ for } t < 0.625\ \mu\text{s for } 400 < \lambda < 700 \text{ nm}$$

$$L_{TLV} = 7.6\, t^{1/4}\ \mathrm{J/(cm^2\ sr)} \text{ for } 0.625 \text{ ms} < t < 0.25 \text{ s for } 400 < \lambda < 700 \text{ nm}$$

$$L_{TLV} = 4.8\ \mathrm{W/(cm^2\ sr)} \text{ for } t > 100 \text{ s for } 400 < \lambda < 700 \text{ nm}$$

Figure 5 illustrates these TLVs® for large sources expressed in terms of radiance.

The measurement aperture should be placed at a distance of 100 mm or greater from the source. For large area irradiation, the reduced TLV® for skin exposure applies as noted in the footnote to "IRB & C," Table 4.

TABLE 3. TLVs® for Extended Source Laser Viewing Conditions

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV®
Light	400 to 700 nm	10^{-13} to 10^{-11}	$1.5\ C_E\ 10^{-8}$ J/cm^2
	400 to 700 nm	10^{-11} to 10^{-9}	$2.7\ C_E\ t^{0.75}$ J/cm^2
	400 to 700 nm	10^{-9} to 18×10^{-6}	$5.0\ C_E \times 10^{-7}$ J/cm^2
	400 to 700 nm	18×10^{-6} to 0.7	$1.8\ C_E\ t^{0.75} \times 10^{-3}$ J/cm^2
	Dual Limits for 400 to 600 nm visible laser exposure for $t > 0.7$ s		
	Photochemical		
	For $\alpha \leq 11$ mrad, the MPE is expressed as irradiance and radiant exposure*		
	400 to 600 nm	0.7 to 100	$C_B \times 10^{-2}$ J/cm^2
	400 to 600 nm	100 to 3×10^4	$C_B \times 10^{-4}$ W/cm^2
	For $\alpha > 11$ mrad, the MPE is expressed as radiance and integrated radiance*		
	400 to 600 nm	0.7 to 1×10^4	$100\ C_B$ J/(cm^2 sr)
	400 to 600 nm	1×10^4 to 3×10^4	$C_B \times 10^{-2}$ W/(cm^2 sr)
		and	
	Thermal		
	400 to 700 nm	0.7 to T_2	$1.8\ C_E\ t^{0.75} \times 10^{-3}$ J/cm^2
	400 to 700 nm	T_2 to 3×10^4	$1.8\ C_E\ T_2^{-0.25} \times 10^{-3}$ W/cm^2

TABLE 3 (con't.). TLVs® for Extended Source Laser Viewing Conditions

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV®	
IRA	700 to 1050 nm	10^{-13} to 10^{-11}	1.5 C_A $C_E \times 10^{-8}$ J/cm^2	
	700 to 1050 nm	10^{-11} to 10^{-9}	2.7 C_A C_E $t^{0.75}$ J/cm^2	
	700 to 1050 nm	10^{-9} to 18×10^{-6}	5.0 C_A $C_E \times 10^{-7}$ J/cm^2	
	700 to 1050 nm	18×10^{-6} to T_2	1.8 C_A C_E $t^{0.75} \times 10^{-3}$ J/cm^2	
	700 to 1050 nm	T_2 to 3×10^4	1.8 C_A C_E $T_2^{-0.25} \times 10^{-3}$ W/cm^2	
	1050 to 1400 nm	10^{-13} to 10^{-11}	1.5 C_C $C_E \times 10^{-7}$ J/cm^2	
	1050 to 1400 nm	10^{-11} to 10^{-9}	27.0 C_C C_E $t^{0.75}$ J/cm^2	
	1050 to 1400 nm	10^{-9} to 50×10^{-6}	5.0 C_C $C_E \times 10^{-6}$ J/cm^2	
	1050 to 1400 nm	50×10^{-6} to T_2	9.0 C_C C_E $t^{0.75} \times 10^{-3}$ J/cm^2	NTE 1.0 J/cm^2
	1050 to 1400 nm	T_2 to 3×10^4	9.0 C_C C_E $T_2^{-0.25} \times 10^{-3}$ W/cm^2	NTE 1.0 J/cm^2

* For sources subtending an angle greater than 11 mrad, the limit may also be expressed as an integrated radiance $L_p = 100\ C_B$ J/(cm^2 sr) for 0.7 s $\leq t < 10^4$ s and $L_e = C_B \times 10^{-2}$ W/(cm^2 sr) for $t \geq 10^4$ s as measured through a limiting cone angle γ.

TABLE 3 (con't.). TLVs® for Extended Source Laser Viewing Conditions

These correspond to values of J/cm^2 for $10\ s \leq t < 100\ s$ and W/cm^2 for $t \geq 100\ s$ as measured through a limiting cone angle γ.

$\gamma = 11$ mrad for $0.7\ s \leq t < 100\ s$
$\gamma = 1.1 \times t^{0.5}$ mrad for $100\ s \leq t < 10^4\ s$
$\gamma = 110$ mrad for $10^4\ s \leq t < 3 \times 10^4\ s$

$T_2 = 10 \times 10^{(\alpha - 1.5)/98.5}$ for α expressed in mrad for $\lambda = 400$ to 1400 nm.

For exposure duration "t", the angle α_{max} is defined as:

$\alpha_{max} = 5$ mrad for $t \leq$ to 0.625 ms
$\alpha_{max} = 200\ t^{0.5}$ mrad for $0.625\ ms < t < 0.25\ s$, and
$\alpha_{max} = 100$ mrad for $t \geq 0.25\ s$
$\alpha_{min} = 1.5$ mrad

TABLE 4. TLVs® for Skin Exposure from a Laser Beam

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV®
UV[A]	180 nm to 400 nm	10^{-9} to 10^{4}	Same as Table 2
	400 nm to 1400 nm	10^{-9} to 10^{-7}	$2\ C_A \times 10^{-2}$ J/cm^2
Light & IRA	“ “	10^{-7} to 10	$1.1\ C_A\ \sqrt[4]{t}$ J/cm^2
	“ “	10 to 3×10^{4}	$0.2\ C_A$ W/cm^2
IRB & C[B]	1.401 to 10^{3} µm	10^{-14} to 3×10^{4}	Same as Table 2

[A]Ozone (O_3) is produced in air by sources emitting ultraviolet (UV) radiation at wavelengths below 250 nm. Refer to Chemical Substances TLV® for ozone.

$C_A = 1.0$ for $\lambda = 400 - 700$ nm; see Figure 2 for $\lambda = 700$ to 1400 nm

[B]At wavelengths greater than 1400 nm, for beam cross-sectional areas exceeding 100 cm^2, the TLV® for exposure durations exceeding 10 seconds is:

$$TLV = (10{,}000/A_s)\ \text{mW/cm}^2$$

where A_s is the irradiated skin area for 100 to 1000 cm^2, and the TLV® is 10 mW/cm^2 for irradiated skin areas exceeding 1000 cm^2 and is 100 mW/cm^2 for irradiated skin areas less than 100 cm^2.

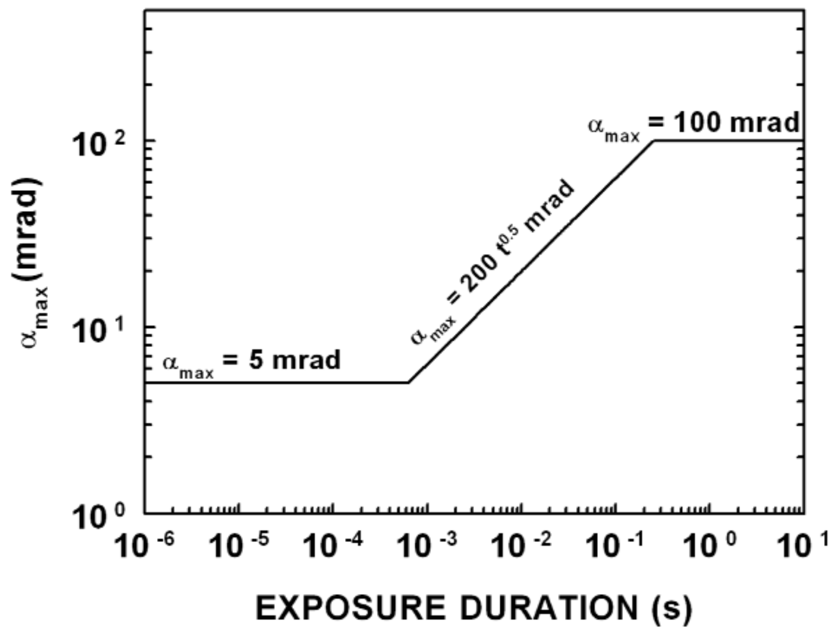

FIGURE 1. Variation of α_{max} with exposure duration.

TLV®–PA

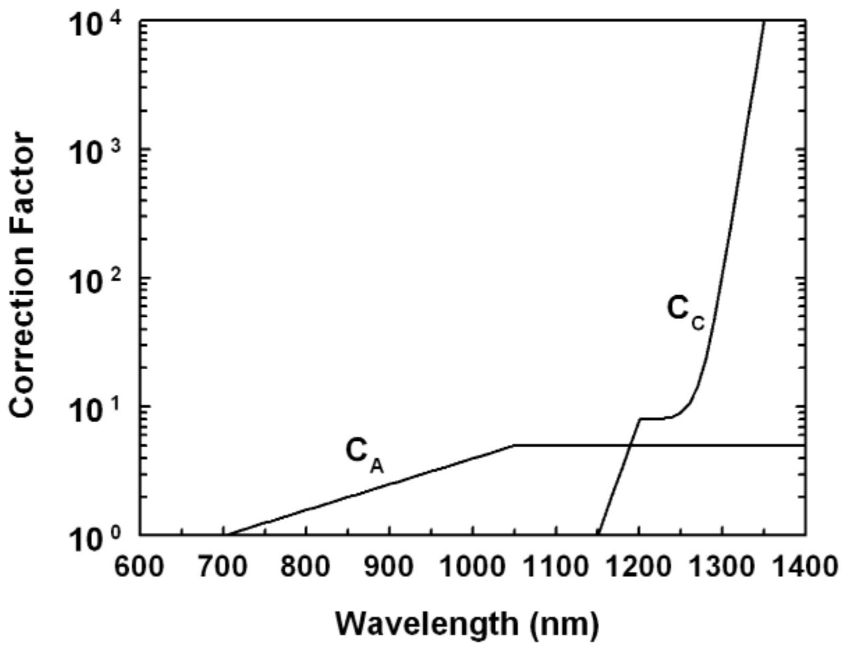

FIGURE 2. TLV® correction factor for λ = 700–1400 nm*
*For λ = 700–1049 nm; $C_A = 10^{(0.002[\lambda - 700])}$; for λ = 1050–1400 nm, C_A = 5.
For $\lambda \leq 1150$, C_C = 1; for λ = 1150–1200, $C_C = 10^{(0.018[\lambda - 1150])}$; for λ = 1200–1250, C_C = 8; and for λ = 1250–1400, $C_C = 7 + 10^{[0.04(\lambda - 1250)]}$.

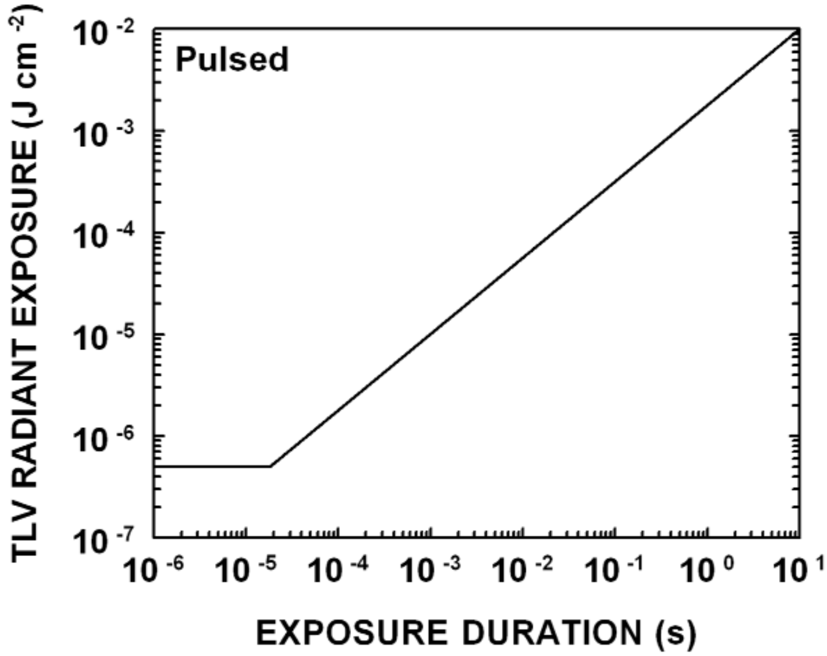

FIGURE 3a. TLV® for intrabeam (direct) viewing of laser beam (400–700 nm).

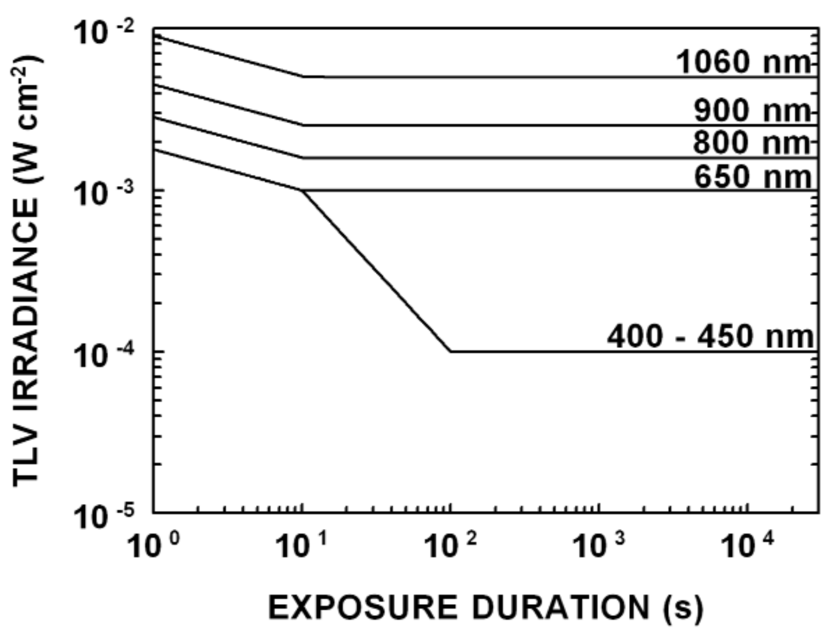

FIGURE 3b. TLV® for intrabeam (direct) viewing of CW laser beam (400–1400 nm).

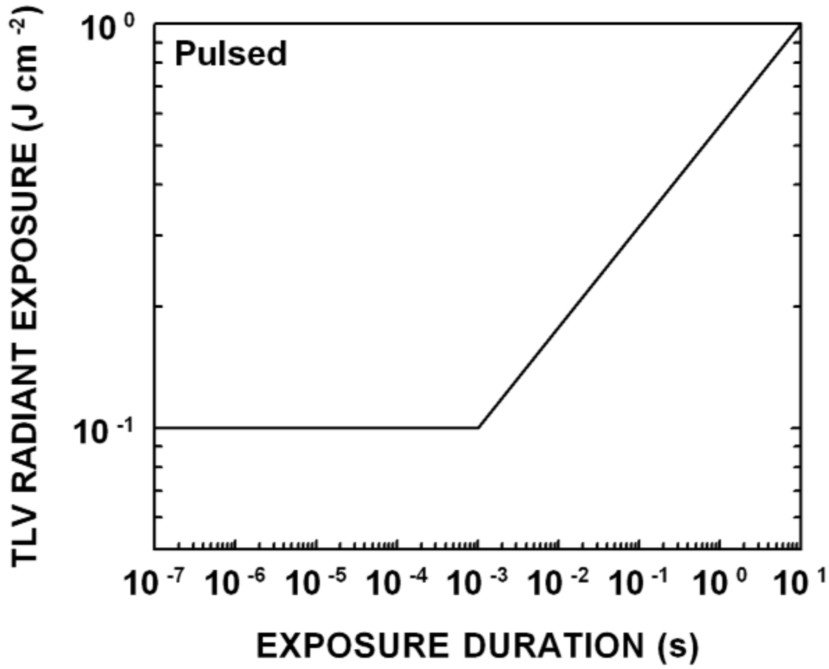

FIGURE 4a. TLV® for laser exposure of skin and eyes for far-infrared radiation (wavelengths greater than 1.4 µm).

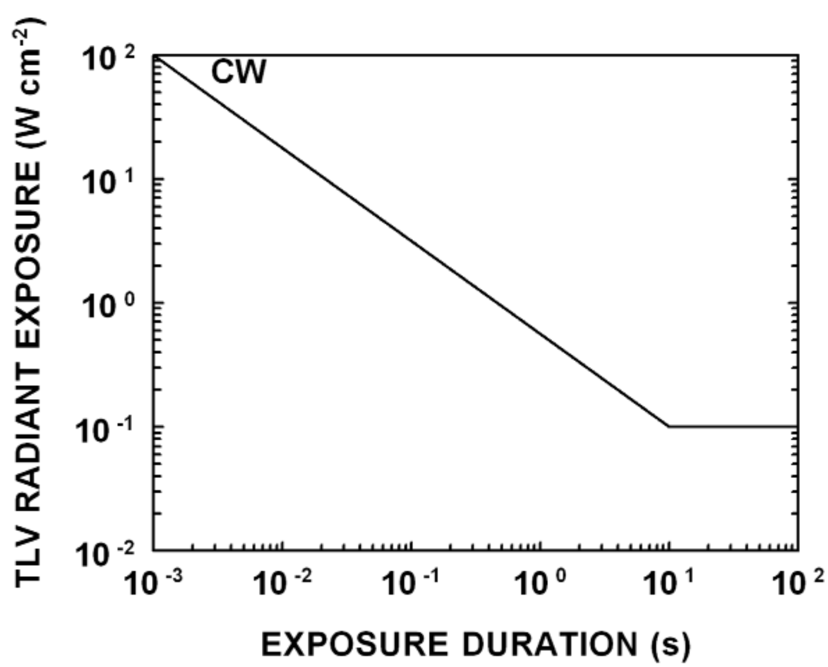

FIGURE 4b. TLV® for CW laser exposure of skin and eyes for far-infrared radiation (wavelengths greater than 1.4 µm).

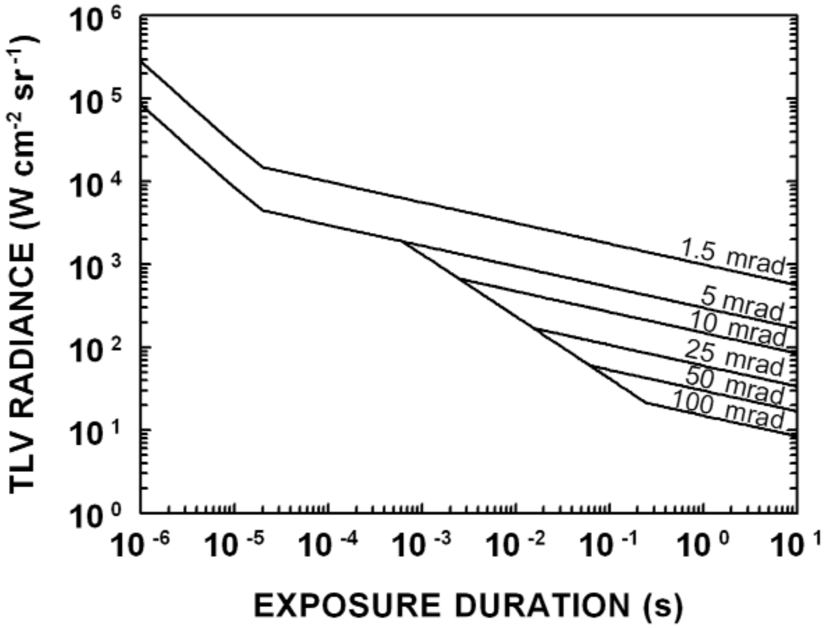

FIGURE 5. TLVs® in terms of radiance for exposures to extended-source lasers in the wavelength range of 400 to 700 nm.

‡ IONIZING RADIATION

The TLV® Physical Agents Committee accepts the occupational exposure guidance of the International Commission on Radiological Protection (ICRP).[1] Ionizing radiation includes particulate radiation (e.g., alpha particles and beta particles emitted from radioactive materials, and neutrons from nuclear reactors and accelerators) and electromagnetic radiation (e.g., gamma rays emitted from radioactive materials and X-rays from electron accelerators and X-ray machines) with energy greater than 12.4 electron-volts (eV), corresponding to wavelengths less than approximately 100 nanometers (nm).

The guiding principle of radiation protection is to avoid all unnecessary radiation exposures. ICRP has established principles of radiological protection. These are:

- *The justification of a work practice*: No work practice involving exposure to ionizing radiation should be adopted unless it produces sufficient benefit to the exposed individuals or the society to offset the detriment it causes.
- *The optimization of a work practice*: All radiation exposures must be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account.
- *The individual dose limits*: The radiation dose from all relevant sources should not exceed the prescribed dose limit in Table 1 (*see* next page).

The guidelines in Table 1 are the dose limits recommended by ICRP for occupational exposures. The ALARA principle is recommended to keep the radiation doses and exposures as much below the guidelines as practicable. The ICRP publication, "General Principles for the Radiation Protection of Workers," reports comprehensively on the principles for the protection of workers from ionizing radiation and develops guidance on the implementation of these principles.[2]

TLV®–PA

References

1. International Commission on Radiological Protection: Information at: http://www.icrp.org/index.html.
2. International Commission on Radiological Protection: ICRP Publication 75: General Principles for the Radiation Protection of Workers. In: Ann. ICRP 27(1): 1–60 (1997).
3. National Council on Radiation Protection and Measurements: Information at: http://www.ncrp.com.

TABLE 1. Guidelines for Exposure to Ionizing Radiation

Type of Exposure	Dose Limits
Effective Dose	
a) in any single year	50 mSv (millisievert)[A]
b) averaged over 5 years	20 mSv per year
Annual Equivalent Dose to:	
a) lens of the eye	150 mSv
b) skin	500 mSv
c) hands and feet	500 mSv
Embryo-Fetus exposures once the pregnancy is known	
• Monthly equivalent dose[B]	0.5 mSv
• Dose to the surface of women's abdomen (lower trunk)	2 mSv for the remainder of the pregnancy
• Intake of radionuclide	1/20 of Annual Limit on Intake (ALI)
Radon Daughters	4 Working Level Months (WLM/year)

[A] 10 mSv = 1 rem

[B] Sum of internal and external exposure but excluding doses from natural sources as recommended by NCRP.[3]

NOTICE OF INTENDED CHANGE — † IONIZING RADIATION

The reason for this NIC is to update guidance on occupational exposure levels with new information from ICRP, NCRP, and national and international recommendations.

ACGIH® has adopted the TLV® for occupational exposure to ionizing radiation from the guidelines recommended by the International Commission on Radiation Protection (ICRP, 2007) and the National Council on Radiation Protection and Measurements (NCRP, 1993). Ionizing radiation includes particulate radiation (α particles and β particles emitted from radioactive materials, and neutrons, protons and heavier charged particles produced in nuclear reactors and accelerators) and electromagnetic radiation (gamma rays emitted from radioactive materials and X-rays from electron accelerators and X-ray machines) with energy > 12.4 electron volts (eV) corresponding to wavelengths less than approximately 100 nanometers (nm).

The guiding principles of ionizing radiation protection are:

- ***Justification:*** No practice involving exposure to ionizing radiation should be adopted unless it produces sufficient benefit to an exposed individual or society to offset the detriment it causes.
- ***Optimization:*** All radiation exposures must be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account.
- ***Limitation:*** The radiation dose from all occupationally relevant sources should not produce a level of risk of greater than about 10^{-3} per year of inducing fatal cancer during the lifetime of the exposed individual.

The TLV® guidelines are the dose limits shown in Table 1. Application of ALARA principles are recommended for all workers to keep radiation exposures as far below the guidelines as practicable.

TABLE 1. Guidelines for Exposure to Ionizing Radiation[A]

Type of Exposure	Dose Limits
Effective Dose	
a) in any single year	50 mSv (millisievert)[B]
b) averaged over 5 years	20 mSv per year
Annual Equivalent Dose[C] to:	
a) lens of the eye	150 mSv
b) skin, hands and feet	500 mSv
Cumulative Effective Dose:	10 mSv × age in years
Embryo/Fetus Monthly Equivalent Dose[C]:	0.5 mSv
Radon and Radon Daughters	4 Working Level Months (WLM)[D]

[A] Doses are the effective doses from combined external and internal sources (excluding background radiation from radon, terrestrial, cosmic and internal body sources). The effective dose is that defined by ICRP and NCRP, where the effective dose is $H_T = \sum w_T \sum w_R D_{T,R}$, in which $D_{T,R}$ is the average absorbed dose in each tissue or organ, w_T is the tissue weighting factor representing the proportionate detriment (stochastic cancer risk), and w_R is the radiation weighting factor for the types of radiation(s) impinging on the body or, in the case of internal emitters, the radiation emitted by the source(s). The values of w_R and w_T to be used are those recommended by ICRP (2007).

[B] 10 mSv = 1 rem.

[C] The equivalent dose is the sum of external and internal absorbed doses multiplied by the appropriate radiation weighting factors.

[D] One WLM = 3.5×10^{-3} Jh/m^3. The upper value for the individual worker annual dose is 10 mSv, which corresponds to an upper activity reference level of 1500 becquerels per m^3 for radon and radon progeny in equilibrium, where a becquerel is a reciprocal second (ICRP, 1993, 2007).