American National Standard

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American National Standard for Safe Use of Lasers Outdoors

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American National Standard for Safe Use of Lasers Outdoors

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American National Standard

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American National Standard for Safe Use of Lasers Outdoors

1. General

1.1 Scope.

This standard provides guidance for the safe use of potentially hazardous lasers and laser systems (0.18 μm to 1 mm), in an outdoor environment. It also provides guidance for controlling disability glare from exposure to non-injurious levels of visible laser light (see Appendix H), which might interfere with sensitive or critical tasks, and guidance for the manufacturers of these open-beam laser systems. Lasers used for fixed, terrestrial point-to-point free-space optical telecommunications are not covered in this document, but will be covered in the revision of ANSI Z136.2-1997.

1.1.1 Visual Interference. Visible laser beams used outdoors, especially at night, for display and other purposes may need additional control measures to protect potentially exposed persons from hazards associated with bright light. These hazards include transient visual effects of laser beams such as flashblindness, afterimage, glare, and startle. These effects can produce indirect safety hazards when people are performing critical visual tasks. Examples of critical tasks include, but are not limited to, operating heavy equipment or motor vehicles, piloting aircraft, or facilitating control tower activities.

For purposes of this standard, visible radiation effects are assumed to occur in the spectral region from 0.38 to 0.78 μm. The exact divisions between visible and invisible radiation depend on the spectral sensitivity of the individual and the radiance of the source (see Appendix H). Spectral ranges such as 0.4 to 0.7 μm or 0.38 to 0.78 μm are defined for convenience and should not be considered as precise delineations between visible and invisible. This standard addresses biological effects, both on vision impairment and on actual injury potential from optical radiation.

1.1.2 Product Performance. Laser systems, which may be used outdoors, that meet the U.S. Federal Laser Product Performance Standard, 21 CFR 1040, herein referred to as the Federal Laser Standard, can be considered as meeting the product performance requirements of this standard. Guidance is contained in 4.3.4 for additional safety features, for lasers and laser systems used outdoors that may be required by the Laser Safety Officer (LSO). Lasers and laser systems that are sold or imported into the U.S. are required to meet the Federal Laser Standard unless a variance or an exemption is obtained from the Food and Drug Administration's Center for Devices and Radiological Health (FDA/CDRH).

1.1.3 Display Products. A variance from the Federal Laser Standard is required for all Class 3B and Class 4 outdoor laser visual display products. Before Class 3B and Class 4 demonstration lasers are used in navigable airspace as defined by the Federal Aviation Administration (FAA), users are required to receive a letter of non-objection from the FAA in addition to the variance from the FDA/CDRH. These steps are federally mandated to ensure that the public is not exposed to hazardous laser radiation and that the laser energy will not interfere with FAA approved flight operations (see 4.6, and Appendices A, E, and F).

1.1.4 Scientific/Other Lasers. Lasers that comply with the Federal Laser Standard and are not used for display products do not require an FDA/CDRH variance to be used outdoors. These include lasers used for scientific purposes, research studies, or industrial use. However, the operators of Class 3B and Class 4 lasers with beams that could enter navigable airspace should receive letters of non-objection from the FAA before operation begins. When such laser beams cross property lines, the property owner should be notified if personal exposure in excess of the maximum permissible exposure (MPE) is possible.

1.1.5 Wireless Optical Communication Systems. Free space optical telecommunications systems utilize lasers to transmit data and/or telephony information via highly collimated beams. These systems usually operate in the near and mid-infrared (invisible) portion of the spectrum (0.78-2.8 μm). Normally, the visual interference aspects of this standard do not apply to these systems. Guidance for these types of systems is not included in this document, but will be provided in the revision of ANSI Z136.2-1997.

1.1.6 Military Coordination. Users of Class 3B and Class 4 lasers operating near or across special use airspace should coordinate with the local military authorities to ensure that the use will not interfere with military or Department of Energy (DoE) operations. When laser beams cross prohibited/restricted areas, even if the MPE is not exceeded in that area, the military authority governing that airspace should be informed due to potential unique military operations. Users of lasers that could interfere with satellite sensors should coordinate with the Department of Defense (DoD) Laser Clearinghouse, U.S. Space Command.

1.1.7 Low-Power Lasers. Class 1, 1M, 2, 2M, or 3R visible lasers that are not intended to expose personnel pose little risk of retinal injury. When personnel exposure is not intended and the lasers are properly used, these lasers are not covered by this standard. Guidance for intentional personnel exposure to Class 2, Class 2M or Class 3R visible lasers by use or design is included in this standard (see 4.2.4).

1.1.8 Direct Fire Simulators. Laser systems are sometimes intentionally pointed at personnel participating in weapons training programs. Guidance is provided for lasers used to simulate direct fire from pistols or rifles, to ensure that the MPE, based on a maximum expected exposure duration, is not exceeded (see 4.2.5).

1.1.9 U.S. Department of Defense (DoD) Laser Purchases. A laser hazard evaluation approved by the appropriate authority for each purchasing service is required for all DoD laser systems intended for outdoor use. The DoD purchasing authority may apply the DoD exemption to the federal requirements of 21 CFR 1040 if the intended use meets appropriate criteria (see Section 10 for alternate criteria).

1.2 Intended Use of this Standard.

This standard is intended as a guide for designers, users, and operators of lasers or laser systems that are used outdoors. It provides specific information for hazard evaluation, implementation of control measures, and education of various laser safety personnel. It also provides uniform guidance for users and managers of laser systems in establishing standard operating procedures (SOPs) and protocols for Class 3B and Class 4 lasers (see Appendix A for sample SOPs). General guidelines for laser safety and hazard assessment can be found in ANSI Z136.1 and Occupational Safety and Health Administration (OSHA) Technical Manuals (see 11.2).

Differences in sensitivity to optical radiation among individuals and anticipation of unusual situations are recognized in this standard. Hazard evaluation is based on the potential of the laser to produce injury or adverse effects. Control measures are intended to help prevent hazardous exposure to personnel through recognized and accepted safety practices, and are not based on the probability of personnel exposure or injury.

1.3 Laser Safety Officer (LSO).

For Class 3B and Class 4 outdoor operations, an individual shall be designated as the LSO by the employer, system owner, and/or property owner as necessary. The LSO shall have both the authority and the responsibility to effect the knowledgeable evaluation of laser hazards and to monitor and enforce their control. The LSO shall be responsible for:

(1) classifying or verifying classification of laser systems under the LSO's jurisdiction

(2) hazard evaluation of laser work areas including establishment of hazard zones

(3) ensuring that the prescribed control measures are in effect

(4) recommending or approving substitute or alternate control measures when the primary ones are not feasible or practical

(5) periodically auditing the functionality of the control measures in use

(6) approving standard operating procedures (SOPs)

(7) recommending or approving protective equipment and ensuring that the protective equipment is audited periodically to ensure it is in proper working order

(8) approving the wording on area signs and equipment labels

(9) approving laser installation facilities and laser equipment prior to use

(10) ensuring that the safety features of the laser installation facilities and laser equipment are audited periodically to assure proper operation

(11) ensuring that adequate safety education and training are provided to personnel within the nominal hazard zone (NHZ)

(12) ensuring that proper medical surveillance is provided for laser personnel

1.4 Applications.

This standard provides guidance for all uses of lasers outdoors (except for fixed, terrestrial point-to-point free-space optical telecommunications systems), for personnel using lasers outdoors, manufacturing lasers for outdoor use, or performing tasks outdoors where potential exposure to laser energy could lead directly or indirectly to personal injury.

1.4.1 Federal Variance. This standard provides guidance for those systems that have received a variance or an exemption from some of the product performance requirements of the Federal Laser Standard. Alternate safety features are provided in this standard, but the FDA/CDRH may require additional or alternate safety features in the variance. Some additional product performance safety features for outdoor laser systems that could be required by the LSO are in Section 4.3.4. This standard also addresses outdoor laser applications that do not require an FDA/CDRH variance and the outdoor use of lasers that may not have been originally intended for outdoor use.

1.4.2 Laser Controlled Area. Guidance is provided for establishing laser-controlled areas in military-controlled airspace or ground areas.

2. Definitions

The definitions of the terms listed below are based on a pragmatic rather than a basic approach. Therefore, the terms defined are limited to those actually used in this standard and its appendices and are not intended to constitute a dictionary of terms used in the laser field as a whole.

absorption. Transformation of radiant energy to a different form of energy by interaction with matter.

accessible emission limit (AEL). The maximum accessible emission level permitted within a particular laser hazard class.

accessible optical radiation. Optical radiation to which the human eye or skin may be exposed for the condition (operation, maintenance, or service) specified.

afterimage. A transient image left in the visual field after an exposure to a bright light.

aided viewing. Viewing with the help of magnifying optics (usually 7×50 binoculars). Viewing with prescription eyeglasses, reading glasses, or contact lenses, that only correct for visual acuity is considered unaided viewing.

alignment mode. Operation of the laser system at the lowest possible power to enhance safety while conducting beam alignment.

alpha (α). See *apparent visual angle*.

alpha-max (α_{max}). The angular limit beyond which extended source MPEs for a given exposure duration are expressed as a constant radiance or integrated radiance. This value is defined as 100 mrad.

alpha-min (α_{min}). See *limiting angular subtense*.

aperture. An opening, window, or lens through which optical radiation can pass.

apparent visual angle (α). The angular subtense of the source as calculated from source size and distance from the eye. While it is expressed in radians (rad), it is not the beam divergence of the source.

attenuation. The decrease in the radiant flux as it passes through an absorbing or scattering medium.

authorized laser operator. A knowledgeable person, present during laser operation, who has been given authority to operate the laser system in compliance with applicable safety standards, subject to recommendations of the LSO.

average power (Φ). The total energy imparted during exposure divided by the exposure duration.

aversion response. Closure of the eyelid, eye movement, pupillary constriction or movement of the head to avoid an exposure to a noxious stimulant or bright light. In this standard, the aversion response is assumed to limit exposure of a specific retinal area to 0.25 sec or less (see Appendix H).

beam. A collection of rays characterized by direction, diameter, (or dimensions), and divergence (or convergence).

beam backstop. A non-specular material that is opaque to laser radiation of a particular wavelength. An adequate backstop encompasses the entire laser beam and appropriate buffer area.

beam diameter (D_L). In this standard, the beam diameter is the radial distance across the center of a laser beam between points where the irradiance is 1/e times the peak beam irradiance (or radiant exposure for a pulsed laser).

beam divergence (ϕ). See *divergence*.

beam waist. The smallest radial dimension of the beam along the beam path.

blindspot. A temporary or permanent loss of vision of part of the visual field.

Appendix H
Visible and Invisible Laser Radiation — Problems in Laser Safety Terminology

Modified from Sliney, D.H., Lund, D. J., and Marshall, W.J., 2002, Visible and invisible laser radiation — problems in laser safety terminology" *J. Laser Appl.*, 14:260-263.

Abstract

The spectral band between 400 nm and 700 nm is termed "visible" in laser safety standards, but it is often unclear to many who work in laser safety that this is not the full extent of the visible spectrum. Light, or visible radiation, is that which is perceived by the human eye, and the spectral bandwidth for vision is really larger, extending into what some refer to as ultraviolet and infrared. This is important to recognize when speaking of visual effects such as after-images and glare. Several important questions arise with regard to this issue. The 400-700 nm spectral band was initially established as the extent of the spectral range for class 2 lasers, but should this spectral band be reconsidered? Indeed what laser wavelengths should be considered "visible" and what should be considered "invisible?"

H1. Background.

Laser safety literature frequently refers to "visible" laser radiation as, "optical radiation in the spectral range between 400 nm (violet light) and 700 nm (red light)." It is technically true that these wavelengths are visible; however, wavelengths shorter than 400 nm and longer than 700 nm are certainly visible, and the extent of the visible band is larger in other technical disciplines, such as vision science and illuminating engineering. In the development of the new ANSI Standard Z136.6, visual effects such as discomfort glare, dazzle, and after-images had to be covered in detail, and the convenient dividing lines of 400 and 700 nm were shown to be inadequate to define this range of visual effects. The International Commission on Illumination—the CIE (Commission International de l'Eclairage)—for a long time defined the visible spectrum as 380-780 nm. The CIE photopic (daylight) luminous efficiency function (i.e., visual sensitivity function), V(λ) had published values from 380 to at least 780 nm for many years (see Figure H1). The V(λ) function is applied worldwide and published widely in books on lighting and vision science. The CIE defines "visible radiation" as "any optical radiation capable of causing a visual sensation directly," and also notes that: "There are no precise limits for the spectral range of vision since they depend upon the amount of radiant power reaching the retina and the responsivity of the observer. The lower limit is generally taken between 360 and 400 nm and the upper limit between 760 and 830 nm."

Many standardization efforts define "light" or visible radiation as a precisely specified band of optical wavelengths that elicit a visual response. However, the human eye can detect ultraviolet (UV) wavelengths in youth down to approximately 310 nm (in the CIE UV-B spectral band), and the shortest wavelengths of detection gradually increase over one's lifetime as a result of yellowing changes in the human crystalline lens to 380-420 nm. The red, long-wavelength "edge" of the visible spectrum is far more difficult to define since the eye's spectral response to red light steadily decreases by approximately one log unit (a factor of 10) with each 35 nm of increasing wavelength. Even 1064 nm (IR-A) laser radiation appears as a deep cherry-red source to a dark-adapted eye staring directly into a Class 1, 1 mW beam in total darkness. Indeed, at 1064 nm, the eye's photopic (cone) spectral response is approximately 10^{-11} that at 500 nm. Figure H1 shows the eye's spectral response as a function of wavelength with a peak at 555 nm.

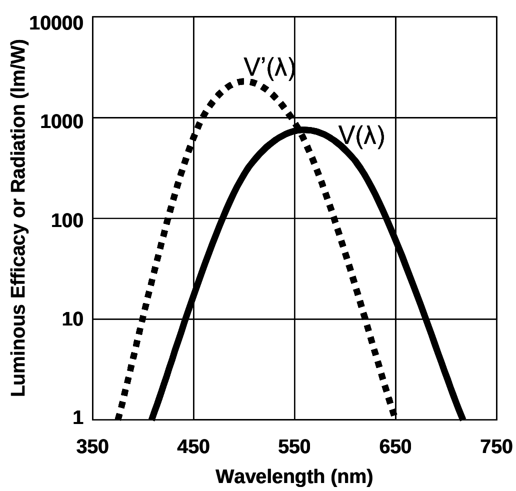

Figure H1. Photopic luminous sensitivity. The eye's photopic (daylight) (spectral response) function [V(λ)] for the CIE standard observer. For comparison, the scotopic (night-vision) function [V′(λ)] is shown as a dashed line.

Note that the full width at half maximum spectral sensitivity points are at 510 and 610 nm, leading to a "spectral bandwidth" of only 100 nm by some conventions. The 10% response points are at 475 and 650 nm, and the 1% values are at approximately 428 and 686 nm (see Figure H1). The sensitivity at 400 nm is only 0.04% and at 700 nm is only 0.4%, showing the current inconsistency in the borderline wavelengths chosen to define Class 2. The gallium-nitride (GaN) family of diode lasers emit very close to the 400 nm dividing line now existing in most laser safety standards for the Class 2 designation. These lasers are clearly visible, but will they produce a strong aversion response? The aversion response occurs with a strong visible stimulus, and is luminance driven rather than radiance driven. Still, it is reasonable to ask: does the wavelength dependency of the aversion response follow the CIE V(λ) response, which is based on levels of luminance much lower than those required to produce an aversion response? The stimulus size also plays a role.

H2. Class 2 "visible" lasers.

The 400-700 nm band now used in laser safety was originally introduced in the 1970-1972 drafting period of the first ANSI Standard (ANSI Z136.1-1973) to define the limits of Class 2 where a *strong* visual stimulus was thought to produce an aversion response. Indeed, today, some visual scientists question whether these spectral bandwidth limits for Class 2 should really be so extensive. The recent series of articles about laser pointer safety has underscored this concern.

The plain fact of the matter is that a wavelength of 401 or 699 nm may not always produce an aversion response, and the outcome of a direct illumination of the eye depends to some extent on the individual subject. Vision scientists have long recognized that the spectral sensitivity of the human eye varies from individual to individual. The CIE luminous efficacy function V(λ) is actually the averaged response of a range of individuals and depends upon the ambient illumination and other factors. For this reason, the CIE long ago adopted the term of "CIE standard observer" — a fictitious person having that averaged, smooth spectral response. This smooth curve was used to develop standards for light measurement and to define the photometric units, the lumen, and the candela. Some individuals have deficits in color vision and this deficit is frequently referred to in the lay literature as "color blindness." There are at least three common types of color deficit, which are referred to as "protanopia" (reduced sensitivity to red light), "deuteranopia" (reduced sensitivity to green, which appears grayish), and "tritanopia" (reduced sensitivity to blue, which is very rare).

One can now only speculate, but in at least one case where an individual claimed to have continuously stared into a red laser pointer (and may have actually been injured), the subject may not have experienced a very strong dazzling effect at 670 nm if he had a reduced visual sensitivity in the red as a result of one type of color deficit (i.e., one type of color blindness known as protanopia).

H3. The "invisible laser."

More amusing is the problem regarding the term invisible laser. The use of this term in safety documents was not meant to infer that the laser itself cannot be seen. Strict English usage requires that the standard wording should be "visible laser radiation" and "invisible laser radiation" as properly used in the Federal Laser Standard. In recent years, the term visible laser has crept into the ANSI standard, and some committee members have attempted to have this grammatical fault corrected (without complete success).

H4. Recommended practice.

The concepts of visibility and the band of visual wavelengths that produces a strong stimulus could be easily separated. A more careful examination of the photopic visual response curve suggests that the 400-700 nm spectral band now used for class 2 should be reconsidered. Perhaps a narrower spectral band is called for, e.g., from 475 to 650 nm where the luminous efficacy has fallen to approximately 10% of its maximal value would be the more logical. Alternatively, one might argue for a narrow band, where the V(λ) has fallen to 5% of its maximal value, i.e., from 455 to 663 nm. It should be noted that the 1% points occur at about 430 and 685 nm. While a narrowing of the visual-aversion response band appears at first to be a radical proposal, it probably could be achieved now, since there would be only few types of lasers affected. At present, the only commonly used continuous wave laser with a wavelength in the 650-700 nm band is the 670 nm GaAlAs diode laser. As diode lasers with wavelengths less than 650 nm have become less expensive, they have virtually replaced the once ubiquitous 670 nm diode laser in laser pointer and alignment applications. Likewise, in the 400-475 nm band, the He-Cd laser, emitting at 442 nm, is well known, but this laser is no longer widely used in any Class 2 laser application. The GaN violet laser is presently produced in very small numbers, and would also be a photochemical retinal hazard. Hence, now is the time to argue for a revision of the spectral band applied to Class 2. An added result of the narrower band is that the most visually efficient wavelengths

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Laser Institute of America
13501 Ingenuity Drive, Suite 128
Orlando, FL 32826
Phone: (407) 380-1553 · Fax: (407) 380-5588
lia@laserinstitute.org · www.laserinstitute.org

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407.380.1553
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www.laserinstitute.org

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