

American National Standard

ANSI Z136.6—2005

American National Standard for Safe Use of Lasers Outdoors



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Revision of
ANSI Z136.6-2000
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American National Standard for Safe Use of Lasers Outdoors

**Secretariat
Laser Institute of America**

**Approved December 22, 2005
American National Standards Institute, Inc.**

American National Standard

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Published by

**Laser Institute of America
13501 Ingenuity Drive, Suite 128
Orlando, FL 32826**

ISBN: #0-912035-66-8

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Foreword

(This introduction is not a normative part of ANSI Z136.6-2005, American National Standard for Safe Use of Lasers Outdoors.)

In 1968, the American National Standards Institute (ANSI) approved the initiation of the Safe Use of Lasers Standards Project under the sponsorship of the Telephone Group.

Prior to 1985, Z136 standards were developed by ANSI Committee Z136 and submitted for approval and issuance as ANSI Z136 standards. Since 1985, Z136 standards are developed by ANSI Accredited Standards Committee (ASC) Z136. A copy of the procedures for development of these standards can be obtained from the secretariat, the Laser Institute of America, 13501 Ingenuity Drive., Suite 128, Orlando, FL 32826 or viewed at www.z136.org.

The present scope of ASC Z136 covers protection against hazards associated with the use of lasers and optically radiating diodes.

ASC Z136 is responsible for the development and maintenance of this standard. In addition to the consensus body, ASC Z136 is composed of standards subcommittees (SSC) and technical subcommittees (TSC) involved in Z136 standards development. At the time of this printing, the following standards and technical subcommittees were active:

SSC-1	Safe Use of Lasers (parent document)
SSC-2	Safe Use of Lasers and LEDs in Telecommunications Applications
SSC-3	Safe Use of Lasers in Health Care Facilities
SSC-4	Measurements and Instrumentation
SSC-5	Safe Use of Lasers in Educational Institutions
SSC-6	Safe Use of Lasers Outdoors
SSC-7	Eyewear and Protective Barriers

TSC-1	Biological Effects and Medical Surveillance
TSC-2	Hazard Evaluation and Classification
TSC-4	Control Measures and Training
TSC-5	Non-Beam Hazards
TSC-7	Analysis and Applications

EWG Editorial Working Group

The six standards currently issued are:

ANSI Z136.1-2000, American National Standard for Safe Use of Lasers (replaces ANSI Z136.1-1993)

ANSI Z136.2-1997, American National Standard for Safe Use of Optical Fiber Communication Systems Utilizing Laser Diode and LED Sources (replaces ANSI Z136.2-1989)

ANSI Z136.3-2005, American National Standard for Safe Use of Lasers in Health Care Facilities (replaces ANSI Z136.3-1996)

ANSI Z136.4-2005, American National Standard Recommended Practice for Laser Safety Measurements for Hazard Evaluation (first edition)

ANSI Z136.5-2000, American National Standard for Safe Use of Lasers in Educational Institutions (first edition)

ANSI Z136.6-2005, American National Standard for Safe Use of Lasers Outdoors (replaces ANSI Z136.6-2000)

This American National Standard provides guidance for the safe use of lasers and laser systems in an outdoor environment, including laser products that have been granted a variance or exemption from the provisions of the federal product performance standard (21 CFR 1040). Products and applications covered include laser light shows, lasers used for outdoor scientific research, and military lasers. In addition to injurious levels of optical radiation, which are covered in other ANSI Z136 standards, this standard covers possible indirect hazards such as visual interference at night to pilots during takeoff and landing.

Development of this standard has been a collaborative effort of members of the SAE G-10 Committee, laser light show industry, DoD, FDA/CDRH, FAA, NASA, laser and laser light show manufacturers, and laser users including scientists and astronomers. This document serves as a companion to the SAE Aerospace Standard AS4970, 21 CFR 1040, FAA Order 7400.2 and related FAA documents, Military Standard 1425, and Military Handbook 828, for determining the hazards from outdoor laser operations.

This standard provides acceptable levels of irradiation in particular defined zones of navigable airspace in order to minimize visual interference to air crews. These zones were created to reduce illumination levels of aircrews during critical phases of flight, primarily during takeoff and landing, in response to numerous incidents of aircraft illuminations that have occurred during the past several years. These defined levels of irradiation may also apply to operators of vehicles other than aircraft. As more powerful commercial off the shelf lasers have become available, the threat to aircraft and other vehicles from illumination by a laser has increased. For visible laser exposure, indirect hazards due to hampered vision have been demonstrated at levels below the levels that would cause permanent eye injury.

This standard has been published as part of the American National Standard Z136 series. The basic document is American National Standard for Safe Use of Lasers, Z136.1. In general, this standard may be used independently of ANSI Z136.1-2000. Instances where additional guidance contained in ANSI Z136.1-2000 is required are noted in this document.

It is expected that this standard will be periodically revised as new information and experience in the use of lasers are gained. Future revisions may have modified content and use of the most current document is required. While there is considerable compatibility among existing laser safety standards, state, federal, and international requirements and standards may differ, particularly with respect to signs, symbols, and control measures.

Suggestions for improvements of the standard will be welcome. They should be sent to the ASC Z136 Secretariat, Laser Institute of America, 13501 Ingenuity Drive, Suite 128, Orlando, FL 32826.

This standard was developed by SSC-6 (Safe Use of Lasers Outdoors) and approved by ANSI Accredited Standards Committee Z136 on the Safe Use of Lasers. Committee approval of the standard does not necessarily imply that all members voted for its approval.

- Ron Petersen, Committee Chair
- Jerry Dennis, Committee Vice-Chair
- Sheldon Zimmerman, Committee Secretary

Notice

(This notice is not a normative part of ANSI Z136.6-2005, American National Standard for Safe Use of Lasers Outdoors.)

Z136 standards and recommended practices are developed through a consensus standards development process approved by the American National Standards Institute. The process brings together volunteers representing varied viewpoints and interests to achieve consensus on laser safety related issues. As secretariat to ASC Z136, the Laser Institute of America (LIA) administers the process and provides financial and clerical support to the committee.

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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 ($\alpha_{\max}$). 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 ($\alpha_{\min}$). 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.

buffer angle. An angle added to the beam divergence or intended laser projection field in order to ensure a protection zone.

buffer area. The projection of the buffer zone around a target, when the ground serves as the beam backstop.

buffer zone. The airspace defined by the buffer angle surrounding the area of intended beam propagation, including all potential locations of the laser beam where hazardous diffuse or specular reflections could occur and where the MPE or visual interference levels are exceeded. It includes the beam divergence and buffer angle, and the full range of the laser beam to the point where the MPE, or any applicable visual interference level is not exceeded. Natural terrain or beam masks may truncate part of this volume.

C_A. Correction factor that increases the MPE values in the near infrared spectral band based upon reduced absorption by the retina and skin tissues.

C_C. Correction factor that increases the MPE values for ocular exposure in the spectral band of 1.150 and 1.400 μm based upon reduced transmission of the ocular media.

C_E. Correction factor that increases the thermal MPE for extended sources (sources that exceed α_{min}).

collateral radiation. Any electromagnetic radiation, except laser radiation, emitted by a laser or laser system that is physically necessary for its operation.

collimated beam. Effectively, a “parallel” beam of light with very low divergence or convergence. See *divergent beam* and *focused beam*.

construction laser. A laser product used outdoors and intended for surveying, leveling, or alignment. Class 3R lasers and below are usually used for these purposes.

continuous wave (CW). The output of a laser that is operated in a continuous rather than a pulsed mode. In this standard, a laser operating with a continuous output for a period ≥ 0.25 s is regarded as a CW laser.

controlled area. An area where the occupancy and activity of those within is subject to control and supervision for the purpose of protection from laser radiation hazards.

convergent beam. See *focused beam*.

cornea. The transparent outer coat of the human eye that covers the iris and the crystalline lens. The cornea is the main refracting element of the eye.

C_P. Correction factor that reduces the thermal MPE for repeated exposure to pulsed sources.

critical exposure distance. The distance along the beam path of a visible laser source beyond which the effective irradiance falls below the critical level.

critical fusion frequency (CFF). The CFF is the highest pulse repetition frequency that can just be detected by the human visual system. Higher frequencies are indistinguishable from a continuous light source.

critical level. The minimum effective irradiance or radiant exposure from a visible laser beam that can interfere with critical task performance due to transient visual effects. This level is defined in Table 5.

critical PRF. The critical PRF is equal to the PRF at which the MPE calculated from average power is equal to the MPE calculated from discrete pulses (see *PRF* and Table 4).

critical zone. Volume of airspace where visual interference by a visible laser beam would compromise safety due to interruption of necessary performance of critical tasks (see 3.4). This zone surrounds the laser-free zone.

dazzle. To lose clear vision from looking at a bright light.

demonstration laser product. Any laser product designed or intended for purposes of visual display of laser beams, entertainment, advertising display, or artistic composition (see 21 CFR 1040).

diameter (D_L). See *beam diameter*.

diffraction. Deviation of part of a beam, determined by the wave nature of radiation and occurring when the radiation passes the edge of an opaque obstacle.

diffuse reflection. Change in the spatial distribution of a beam of radiation when it is reflected in many directions by a surface or by a medium.

NOTE: Flat finish paints or rough surfaces will generally produce a diffuse reflection and an image will not be observed in the reflection. Surfaces that appear diffuse may produce a specular reflection at far infrared wavelengths. The amount and spatial distribution of energy reflected depends on the illuminating wavelength and the surface texture.

direct-fire simulator. Device designed to simulate the effects of live-fire weapons with a laser beam (for combat training).

disability glare. Obscuration of an object in a person's field of vision due to a bright light source located near the same line-of-sight.

display screen. A matte surface or screen used to display laser light, i.e., the diffused reflection or transmission from the screen is intended to be viewed.

distraction. In this standard, the redirection of attention from the original focus due to sudden exposure to a bright light source.

divergence (ϕ). In this standard, the divergence is the increase in the diameter of the laser beam with distance from the exit aperture, based on the full angle at the point where the irradiance (or radiant exposure for pulsed lasers) is 1/e times the maximum value.

divergent beam. A laser beam that diverges from the exit port at an angle significantly greater than the diffraction limit of the optics system. In this standard, a divergent beam does not have an external beam waist (not a focused beam).

effective energy (Q_{eff}). The energy that passes through the measurement aperture reduced by any applicable transmission loss from optical viewing aids.

effective irradiance. The actual irradiance multiplied by a factor from Table 1, to correct for visual perception. The effective irradiance is compared with the applicable visual interference level. When multiplied by 683, the effective irradiance is the illuminance.

effective power (Φ_{eff}). The power that passes through the measurement aperture reduced by any applicable transmission loss from optical viewing aids.

effective radiant exposure. The effective irradiance multiplied by the exposure duration (see *effective irradiance* above).

electromagnetic radiation. The flow of energy consisting of orthogonally vibrating electric and magnetic fields. This radiation includes optical radiation, X-rays, and radio waves.

electronic monitoring. A variety of means (other than human observers), such as radar or infrared cameras, for observing the sky to prevent potential illuminations of aircraft by laser beams.

emission indicator. An indicator that signals emission in excess of the Class 1 AEL. See *laser armed indicator*, *laser firing indicator* and *Federal Laser Standard*.

energy. The capacity for doing work. Energy content is commonly used to characterize the output

from pulsed lasers, and is generally expressed in joules (J).

exempted laser. Lasers exempted from the requirements of the Federal Laser Standard. The Department of Defense and Department of Energy produce and purchase certain types of lasers that are exempt.

extended source. A source of radiation that subtends an angle larger than α_{min} . These sources include diffuse reflections in close proximity to the viewer, and the emitting sources of some laser projection systems.

Federal Laser Standard. The Federal Laser Product Performance Standard, 21 CFR 1040.10 and 1040.11, governing the import and manufacture of laser systems. The Federal Laser Standard, administered by the Center for Devices and Radiological Health, U.S. Food and Drug Administration (FDA/CDRH), specifies performance, labeling, and informational requirements for lasers and laser systems manufactured after 1976 and introduced into U.S. commerce or imported.

flashblindness. A visual interference effect that persists after the source of illumination has been removed.

flight hazard zones. Flight hazard zones are locations within navigable airspace for which the FAA has established levels of effective irradiance and effective radiant exposure that are less than the *MPE*. These flight hazard zones are the *sensitive zone*, *critical zone*, and *laser-free zone*. Airspace outside these zones is the normal flight zone where levels of irradiance and radiant exposure less than the *MPE* have not been established.

focal length. The distance from the secondary nodal point of a lens to the primary focal point. In a thin lens, the focal length is the distance between the lens and the focal point for a collimated optical source.

focal point. The point toward which radiation converges or from which radiation diverges or appears to diverge.

focused beam. A laser beam that narrows at a distance away from the source, i.e., the beam waist is along the beam path in front of the laser. Lasers that have the beam waist inside the laser cavity or behind the laser are not considered focused in this standard.

free space optical communications system (FSOCS). For purposes of this standard, a fixed terrestrial point-to-point through-the-air system typically used, intended or promoted for voice, data or multimedia telecommunications and/or control

purposes via the use of modulated optical radiation produced by a laser or LED.

Gaussian beam profile. The profile of a laser beam when the laser is operating in the lowest transverse mode (TEM_{00}).

glare. See *disability glare*.

guard. A person with the authority to prevent entry into a hazardous area.

half-power point. The point in time where either the leading or trailing edge of a laser pulse is equal to one-half of its maximum value.

hertz (Hz). The unit that expresses the frequency of a periodic oscillation. One Hz equals one cycle per second.

illuminance (L_v). A measure of the irradiance on a surface multiplied by an appropriate factor to adjust for human visual sensitivity. Measurement units are foot-candle (lumens per square foot) or lux (lumens per square meter). See *effective irradiance*.

incidental personnel. Those persons whose work makes it possible (but unlikely) that they will be exposed to laser energy sufficient to damage their eyes or skin.

infrared radiation. In this standard, optical radiation with wavelengths greater than that defined as visible radiation, i.e., greater than $0.78\ \mu\text{m}$ (see 1.1.1).

integrated radiance (L_p). The integral of the radiance over the exposure duration. Also known as pulsed radiance. The units are joules per square centimeter per steradian ($\text{J cm}^{-2}\text{ sr}^{-1}$).

interlock. A device that is activated upon entry to a laser laboratory or enclosure to terminate laser operation or reduce personnel exposure to below the MPE.

invisible laser. In this standard, an invisible laser emits radiation at a wavelength outside the spectral range defined as visible radiation, i.e., outside of the wavelength range of 0.38 to $0.78\ \mu\text{m}$ (see 1.1.1). This term means that the laser beam, or any reflections, cannot be seen.

iris. The circular pigmented membrane that lies behind the cornea. The iris is perforated by the pupil.

irradiance (E) (at a point of a surface). Quotient of the radiant flux incident (from a particular direction) on an element of the surface containing the point at which irradiance is measured, by the area of that element. Unit: watt per square centimeter (W cm^{-2}).

joule (J). A unit of energy. 1 joule = 1 watt second.

Lambertian surface. An ideal surface whose emitted or reflected radiance is independent of the viewing angle. In this standard, it is also referred to as a matte surface. A diffuse reflection is produced from a Lambertian or matte surface.

laser. A device that produces radiant energy predominantly by stimulated emission. Laser radiation may be highly coherent temporally, or spatially, or both. An acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation.

laser aiming device. A collimated visible or infrared laser device designed either to be hand held or mounted on a weapon system to aid in pointing.

laser armed indicator. An indicator that signals that the laser system is ready to emit laser radiation.

laser controlled area. An area on the ground or in restricted airspace designated for use of Class 3B or Class 4 lasers, and having restricted access.

laser firing indicator. An indicator that provides a visual or audible signal whenever the laser system is actually emitting laser radiation.

laser-free exposure distance. The distance along a visible laser beam path beyond which the laser irradiance is below the laser-free level.

laser-free level. The maximum effective irradiance or radiant exposure of a visible laser beam that is not expected to cause any visual interference to an individual performing critical tasks. This level is defined in Table 5.

laser-free zone. A designated area or volume of airspace where visible optical radiation above the laser-free level could interfere with safety.

laser light show system. A demonstration laser product for producing and redirecting laser beams to produce a visual effect (see 4.2.1).

laser operator. See *authorized laser operator*.

laser personnel. Persons who routinely work around hazardous laser beams where they are normally fully protected by engineering controls or administrative procedures, or both.

laser product. Any manufactured product or assemblage of components that constitutes, incorporates, or is intended to incorporate a laser or laser system. A laser or laser system intended for use as a component of an electronic product shall itself be considered a laser product.

laser safety officer (LSO). An individual with both the authority and the responsibility to monitor and

enforce the control of laser hazards and to effect the knowledgeable evaluation and control of Class 3B and Class 4 laser hazards.

laser safety specialist. One who has formal training or equivalent professional experience to calculate or determine laser hazards and appropriate control measures.

laser system. An assembly of electrical, mechanical, and optical components which includes a laser.

laser system management organization (LSMO). The organization that is responsible for employing and designating a laser safety officer (LSO). This organization may, or may not, own the laser.

laser target designator. A device that emits a collimated beam of laser pulses to electro-optically identify targets.

LIDAR. A term for Light Detection and Ranging (sometimes referred to as laser radar).

light. In this standard, optical radiation with wavelengths between 0.38 and 0.78 μm .

limiting angular subtense ($\alpha_{\min}$). The apparent visual angle that distinguishes a small source from an extended source (see 8.2.2 for criteria).

limiting aperture (D_l). The diameter of the circular area over which irradiance or radiant exposure is averaged for comparison with the MPE.

limiting exposure duration ($T_{\max}$). An exposure duration that is specifically limited by the design or intended use(s).

maintenance. Performance of those adjustments or procedures specified in user information provided by the manufacturer with the laser or laser system that are to be performed by the user to ensure the intended performance of the product. It does not include operation or service as defined in this section.

matte surface. A reflecting surface that scatters incident laser radiation, rather than producing a specularly reflected beam (see *Lambertian surface*).

maximum permissible exposure (MPE). The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin. The criteria for MPE for the eye and skin are detailed in Section 8.

Mie scattering. Atmospheric scattering by particles larger than those that produce Rayleigh scattering. Mie scattering is mostly forward scattering and is less wavelength dependent than Rayleigh scattering.

navigable airspace. Airspace that can contain aircraft. In this standard, navigable airspace is defined as airspace that is 500 feet (152 m) from any structure in semi-populated areas. In heavily populated areas, aircraft are required to allow more distance from structures. Near airports or heliports, navigable airspace extends to the runway. Helicopter operations may require additional considerations, since they often fly below 500 feet.

nodal point. One of two conjugate points inside a thick lens where the angular magnification is unity.

nominal hazard zone (NHZ). The NHZ describes the space within which the level of the direct, reflected, or scattered radiation during operation exceeds the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the applicable MPE level.

nominal ocular hazard distance (NOHD). The distance along the axis of the laser beam beyond which the appropriate MPE is not exceeded (referred to as r_{NOHD} in ANSI Z136.1). The NOHD when considering the potential use of optical viewing aids is referred to as NOHD-M.

operation. The use of the laser product over the full range of its intended functions. It does not include maintenance or service as defined in this section. This definition applies to both the FDA/CDRH standards and DoD "concepts of operation."

operator controlled space. An area on the ground or volume of airspace where the operator has the capability and responsibility for immediately terminating laser operation when a potentially hazardous situation arises.

optical density ($D(\lambda)$, D_λ or OD). The logarithm to the base ten of the reciprocal of the transmittance at a particular wavelength: $D(\lambda) = \log_{10} [1/\tau(\lambda)]$, where $\tau(\lambda)$ is the transmittance at the wavelength of interest.

optical sight. An optical system that allows the user to view the intended target of a laser beam, e.g., a telescope. Crosshairs or some other means are used to align the beam's center with the optical system.

outdoors. In this standard, a location for a laser where the insertion of a mirror into the output beam path could create a specular reflection that extends indefinitely. However, if the reflected beam thus created does not exceed the MPE anywhere along the beam path that is outside of a building, or one of the *visual interference levels* within the corresponding visual interference zone, the location need not be considered as outdoors.

pointing accuracy. The maximum angle of expected error in beam direction during all projected uses of the device. For automatic tracking systems, the pointing accuracy includes the maximum error that could occur during a loss of track scenario before the laser is disabled.

point source. See *small source*.

polarization. The state of radiation where the electric and magnetic field vectors are aligned in a particular orientation.

power. The rate at which energy is emitted, transferred, or received. Unit: watts (joules per second).

PRF. Abbreviation for pulse repetition frequency (see *repetitive pulse laser*).

prohibited/restricted areas. Airspace or ground space in which unauthorized personnel or aircraft are not permitted due to reasons of national security, or where hazardous activities are conducted, e.g., artillery/missile firings or air to ground combat with live munitions, without prior permission of the authorized user, e.g., Department of Energy (DoE) or DoD.

protected switch. A switch that is designed to minimize the possibility of inadvertent activation (sometimes referred to as a “guarded switch”).

protection distance. The distance from the laser beyond which a particular level or limit of irradiance or radiant exposure is not exceeded (see *laser-free exposure distance*, *critical exposure distance*, *sensitive exposure distance*, and *nominal ocular hazard distance*).

pulse duration. The duration of a laser pulse, usually measured as the time interval between the half-power points on the leading and trailing edges of the pulse.

pulsed laser. A laser that delivers its energy in individual pulses lasting less than 0.25 s (see *repetitive pulse laser*).

Q-switched laser. A laser that emits short (~ 10 ns to $1\ \mu\text{s}$), high-power pulses by means of a Q-switch device.

radian (rad). A unit of angular measure equal to the subtended angle at the center of a circle by an arc whose length is equal to the radius of the circle. $1\ \text{radian} = 57.3\ \text{degrees}$; $2\pi\ \text{radians} = 360^\circ$.

radiance (I_e). Radiant flux or power output per unit area per unit source solid angle. Unit: watts per square centimeter per steradian ($\text{W cm}^{-2}\ \text{sr}^{-1}$).

radiant energy (Q). Energy emitted, transferred, or received as radiation. Unit: joule (J).

radiant exposure (H). Surface density of the radiant energy received. It is computed from the emitted energy divided by the area of the laser beam. Unit: joules per square centimeter (J cm^{-2}).

radiant power (flux) (Φ). Power emitted, transferred, or received as radiation. Unit: watt (W).

Rayleigh scattering. Scattering of radiation during its passage through a medium containing particles whose sizes are very small compared with the wavelength of the radiation (see also *Mie Scattering*).

reflectance. The ratio of total reflected radiant power to total incident power. Also called reflectivity.

reflection. Propagation of radiation in the backward direction following an incidence on a surface. Reflection can be either a *diffuse reflection* or a *specular reflection*.

repetitive pulse laser. A laser with multiple pulses of radiant energy occurring in a sequence.

restricted airspace. See *prohibited/ restricted areas*.

reticule. A network of fine lines, dots, cross hairs, or wires in the focal plane of the eyepiece of an optical instrument.

retinal hazard region. Spectral region between $0.4\ \mu\text{m}$ and $1.4\ \mu\text{m}$.

safety interlock. A device that is activated upon displacement or removal of a protective housing and that prevents human access to hazardous laser radiation while activated.

safety observer. A person who has the responsibility for ensuring that people do not enter areas that contain hazardous laser beams, and has the authority to terminate the laser beams when a potential hazard occurs.

saturable absorption. A decrease in the optical density (bleaching) of an absorptive medium when exposed to high radiant flux or radiant exposure. This effect is normally reversible when the radiation source is removed.

scanning laser. A laser whose beam has a time-varying direction, origin, or pattern of propagation with respect to a stationary frame of reference.

scintillation. The rapid changes in irradiance levels in a cross-section of a laser beam produced by

atmospheric turbulence or other means (see Appendix C).

sensitive exposure distance. Distance along a visible laser beam path beyond which the local irradiance falls below the *sensitive level*.

sensitive level. The minimum effective irradiance or radiant exposure of a visible laser beam that can cause temporary vision impairment, which can interfere with performance of vision-dependent tasks. The effects from illumination at this level can often exceed the duration of exposure (afterimages or flashblindness). This level is defined in Table 5.

sensitive zone. All areas outside the *critical zone(s)* that local authorities, i.e., FAA, local departments of aviation, military, range officers, harbor masters, etc., have identified as needing protection due to anticipated high visual workload. The sensitive zone may or may not be contiguous or concentric with a *critical zone*.

service. The performance of those procedures or adjustments described in the manufacturer's service instructions, which may affect any aspect of the performance of the laser or laser system. It does not include maintenance or operation as defined in this section.

shall. In this document, the word "shall" is to be understood as mandatory.

should. In this document, the word "should" is to be understood as advisory.

site LSO. An LSO for a local facility where lasers are used who is responsible for approving all uses of the lasers or laser systems at that facility. The site LSO may delegate this responsibility to another qualified LSO.

skin hazard distance. The distance from the laser along the beam path to the point beyond which the skin hazard MPE is not exceeded.

small source. A source with an angular subtense smaller than $\alpha_{\min}$. This includes sources sometimes referred to as "point sources" (see 8.2.2 for criteria).

source. A laser or a laser-illuminated reflecting surface.

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

source solid angle (Ω). The area of the apparent emitting area of the source, taken at $1/e$ of peak irradiance points, divided by the square of the viewing distance (distance from the source to the cornea). The source solid angle is expressed in steradians (sr).

special use airspace. Airspace designated by the FAA in order to segregate non-participating aircraft from hazardous activities. Some examples are restricted areas, warning areas, military operating areas, prohibited areas, and alert areas.

specular reflection. A mirror-like reflection.

startle. In this standard, an involuntary movement or reaction resulting from a sudden or unexpected stimulus, such as a bright light abruptly appearing in one's field of view.

steradian (sr). The unit of measure for a solid angle. There are 4π steradians about any point in space (see *source solid angle*).

target area. An area on the ground around the aiming point of the laser that includes all targets.

$T_{\max}$. See *limiting exposure duration*.

$t_{\min}$. The maximum exposure duration for which the MPE is the same as it is for 1 ns.

transmission. Passage of radiation through a medium.

transmittance. The ratio of transmitted power to incident power.

ultraviolet radiation (UV). Optical radiation with wavelengths less than that defined as visible radiation, i.e. less than $0.38 \mu\text{m}$ (see 1.1.1).

unaided viewing. Viewing without the help of magnifying optics. Viewing with optical aids that correct for visual acuity, e.g., spectacles, contact lenses, is considered aided viewing.

variance. In this standard, permission from FDA/CDRH for a laser manufacturer and/or operator to deviate from one or more requirements of the Federal Laser Standard when alternate steps are taken to provide equivalent safety.

viewing distance. The distance from a laser source to an imaginary viewer located at the place where hazard analysis is being performed. This distance is expressed in centimeters (cm).

viewing port. A window provided for viewing inside an enclosure or room where a laser is operating.

visible laser. In this standard, a laser operating in the wavelength range defined as visible radiation, i.e., 0.38 to $0.78 \mu\text{m}$. This term means that scattering or reflection of the laser beam can be seen.

visible radiation (light). Electromagnetic radiation that can be detected by the human eye (see Appendix H). This term is commonly used in laser safety

standards to describe wavelengths that produce a strong visual stimulus (0.4 to 0.7 μm). However, in this standard, visible radiation includes wavelengths in the spectral region from 0.38 to 0.78 μm (see 1.1.1).

visual interference level. The minimum effective irradiance or radiant exposure, of a visible laser beam, that is less than the MPE, but can produce a visual response that interferes with the safe performance of sensitive or critical tasks by aircrew or other personnel. This level varies in accordance with the particular zone that the laser beam traverses. Visual interference level is a generic term for *critical level*, *sensitive level*, or *laser-free level* (see Table 5).

watt (W). The unit of power or radiant flux. 1 watt = 1 joule per second.

wavelength (λ). The distance in the line of advance of a sinusoidal wave from any one point to the next point of corresponding phase. (For example, the distance from one peak to the next.)

wireless communications laser. See *free space optical communications system*.

3. Classification and Hazard Evaluation

3.1 General.

The application of an outdoor laser or laser system influences the total hazard evaluation and thereby influences the application of control measures. The laser classification scheme is based on the laser or laser system's capability of injuring personnel. Any laser or laser system shall be classified according to its accessible radiation during operation.

In addition to the potential for injuring personnel, other aspects of a hazard evaluation include the laser's capability for interfering with task performance, the environment in which the laser is used, and the personnel who may use or be exposed to laser radiation. Visual interference levels are based on these other aspects.

Classification in conformance with the Federal Laser Standard may be used to satisfy the classification requirements of this standard, although it should be noted that in some cases differences exist between this standard and the Federal Laser Standard. If the laser has been modified, subsequent to classification by the manufacturer, the laser may be reclassified according to ANSI Z136.1 under the supervision of the LSO.

3.2 Laser Classification.

Lasers are normally classified by the manufacturer in accordance with the Federal Laser Standard from Class I (least hazardous) to Class IV (most hazardous). The Federal Laser Standard provides accessible emission limits (AELs) for all classes directly. It should be noted that differences exist between the Federal Laser Standard and the ANSI Z136 series of standards.

For example, Class 3 lasers, with wavelengths shorter than 0.4 μm or longer than 0.7 μm , that do not exceed the Class 1 AEL by more than 5 times are classified as Class 3R according to this standard and Appendix H of ANSI Z136.1-2000, but would be classified Class IIb by the Federal Laser Standard. In accordance with Laser Notice 50, the FDA/CDRH will accept classification in accordance with IEC 60825-1, Ed. 1.2, 2001-08, but a notation shall be included on the compliance label.

Lasers may have to be reclassified in accordance with ANSI Z136.1 when used in a particular setting where the laser parameters are modified from those provided by the manufacturer. Lasers manufactured under an FDA/CDRH exemption are often classified in accordance with ANSI Z136.1.

Lasers classified according to the Federal Laser Standard, IEC 60825-1, or ANSI Z136.1 meet the classification requirements of this document. When a laser needs to be reclassified using a standard other than the Federal Laser Standard, and will be used outdoors, classification shall be determined at the most hazardous accessible position along the beam path.

See Section 9 for measurement conditions and Appendix B for examples of hazard classification. See Tables 1 and 2 of ANSI Z136.1 for examples of AELs for various hazard classes.

3.2.1 Classification Criteria. The Classification AELs depend on the MPE, limiting aperture size, and other factors. Whether a specific laser qualifies for a specific laser hazard class depends on the power or energy per pulse transmitted through the measurement aperture, which is located at a specific measurement distance. Selected MPEs are provided in Table 2. The MPE depends on the wavelength, maximum exposure duration, and other output parameters. For most lasers, a maximum exposure duration for classification is assumed to be no more than 100 s. However, for nearly collimated visible and infrared lasers used outdoors, a maximum exposure duration of 10 s is usually sufficient, but may be adjusted by the LSO, if necessary (see 8.2.3).

For optically aided viewing, the measurement aperture and transmission values of common optical systems are listed in Table 3 (see 3.2.6.2). For unaided viewing, the measurement aperture is the limiting aperture. See 9.3 for measurement conditions. For optically aided viewing, the power or energy transmitted through the measurement aperture is multiplied by the appropriate transmission value. The power or energy transmitted through the appropriate measurement aperture at the appropriate measurement distance for either unaided or optically aided viewing, is compared to the AEL for a particular class for that viewing condition (see 3.2.6).

3.2.2 Class 1 and Class 1M. Class 1 lasers are not considered hazardous to the eyes or skin under unaided and optically aided viewing conditions (as described in Table 3). In order for a laser that is used outdoors to be Class 1, the Class 1 AELs for both unaided and optically aided viewing (when applicable) should be considered (see 3.2.6.2).

NOTE: In this standard, Class 1 does not include Class 1M.

(1) Lasers whose effective power or effective energy does not exceed the corresponding Class 1 AEL (for both aided and unaided viewing) are Class 1.

(2) For those lasers with an effective energy for unaided viewing that does not exceed the Class 1 AEL, and have an effective energy for optically aided viewing that exceeds the Class 1 AEL but does not exceed the Class 3B AEL, the hazard Class is 1M.

NOTE: The ANSI Z136.1 standard defines the Class 1 AEL as the product of the MPE and the area of the limiting aperture (for either unaided or optically aided viewing). Note that the MPE for optically aided viewing may be larger than it is for unaided viewing. Lasers previously classified as Class 2a are considered Class 1 by this standard.

3.2.3 Class 2 and Class 2M. A Class 2 laser system emits in the visible portion of the spectrum (0.4 to 0.7 μm) and eye protection is normally afforded by the aversion response including the blink reflex (see Appendix H).

NOTE: In this standard, Class 2 does not include Class 2M.

(1) Lasers with an effective power less than 1 mW CW, or that do not exceed the Class 1 AEL for 0.25 s exposure duration (for both aided and unaided viewing) are Class 2.

(2) For those lasers with an effective energy for unaided viewing that does not exceed the Class 2

AEL, and have an effective energy for optically aided viewing that exceeds the Class 2 AEL, but does not exceed the Class 3B AEL, the hazard class is 2M.

3.2.4 Class 3. A Class 3 laser system (medium power) may be hazardous under direct and specular reflection viewing conditions, but the diffuse reflection is usually not a hazard. A Class 3 laser system is normally not a fire hazard. Class 3 lasers are separated into two subclasses: Class 3R (formerly 3a) and Class 3B.

(1) Class 3R lasers include lasers that produce either visible or invisible beams and include those Class 3 lasers that:

(a) emit less than 5 times the Class 2 AEL for wavelengths between 0.4 and 0.7 μm or

(b) emit less than 5 times the Class 1 AEL for other wavelengths.

In this standard, Class 3R lasers shall meet the Class 3R AEL anywhere along the beam path beyond the specified measurement distances (see 9.3).

NOTE: In this standard, lasers classified Class 3R and lower includes Class 1, Class 1M, Class 2, Class 2M, lasers formerly classified as Class 3a, as well as Class 3R (see Appendix H, ANSI Z136.1-2000, or latest revision thereof).

(2) Class 3B lasers include other Class 3 lasers that:

(a) emit less than 500 mW average power for a duration of 0.25 s or more (total energy of 125 mJ in 0.25 s), and

(b) for pulsed lasers, emit less than 125 mJ/pulse for wavelengths that are not in the retinal hazard region, and less than 30 C_A mJ/pulse (not to exceed 125 mJ) for wavelengths in the retinal hazard region (0.4 to 1.4 μm). Therefore, Class 3B visible lasers are limited to 30 mJ and Class 3B near infrared lasers are limited to 125 mJ, or less, depending on the wavelength.

(c) Class 3B lasers that exceed the Class 3R AEL by more than 5 times are considered higher-power Class 3B lasers in this standard.

3.2.5 Class 4. The most powerful lasers are Class 4. A Class 4 laser system (high power) is a hazard to the eye or skin from the direct beam and sometimes from a diffuse reflection and also can be a fire hazard. Lasers that emit more than 500 mW of power for 0.25 s or longer (125 mJ within 0.25 s), or emit more than the Class 3B energy per pulse limit are considered Class 4.

3.2.6 Use of Apertures. The MPEs relate to biological injury thresholds only when appropriate limiting and measurement apertures are applied (see Table 3). Except for the retinal hazard region (0.4 μm to 1.4 μm), hazard classification is based on corneal hazards. In the retinal hazard region, the diameter of the pupil of the eye is standardized as 7 mm, which is almost the largest pupil that a person would have under any illumination. In the retinal hazard region, the power (or energy) that enters this pupil may be focused to a small spot on the retina. For safety calculations, the size of the beam entering the pupil is not related to the hazard to the retina.

Two basic viewing conditions are considered for retinal and corneal hazards: unaided viewing and optically aided viewing. Common optics, e.g., binoculars and telescopes, transmit and focus laser energy for many laser wavelengths outside the retinal hazard region, as well as within. For lasers used outdoors, hazard classification should be based on the maximum hazard class considering both unaided and optically aided viewing conditions.

3.2.6.1 Unaided Viewing. The measurement aperture that determines laser classification for unaided viewing in the retinal hazard region is the same as the limiting aperture for the eye. Classification is determined by the power or energy transmitted through the measurement aperture, not by the total emitted power or energy. For extended sources, an extended source correction factor, C_E , is applied to the MPE (see 8.2.2).

3.2.6.2 Optically Aided Viewing. The hazard classification shall include the potential use of optical aids when their use is anticipated (as determined by the LSO). For lasers used outdoors, the potential use of magnifying optics by personnel on the ground is usually considered. For beams larger than 7 mm, viewing with optics usually presents a greater hazard than unaided viewing. However, there are a few instances where unaided viewing still indicates a greater hazard due to transmission losses within the optics or an increased retinal image size.

Classification is based on the measurement apertures and transmission losses as listed in Table 3. When extended sources are evaluated, the extended source correction factor, C_E , is applied to the MPE based on an increased source size (usually based on 7×50 binoculars, see 9.3.2).

3.2.7 Visible and Near IR (0.4 – 1.4 μm). This spectral region is termed the retinal hazard region because the ocular media transmits radiant power or energy to the retina of the eye.

3.2.8 Short UV and Far IR (<0.302 μm and > 4.0 μm). For some wavelengths in the short ultraviolet and far infrared portions of the spectrum (less than 0.302 μm and greater than 4.0 μm), optical viewing devices transmit less than 2% of the incident power and would not be more hazardous than from unaided viewing. Therefore, the measurement aperture is the same as the limiting aperture, since unaided viewing will be the most hazardous situation. When the laser beam size is larger than the limiting aperture, the irradiance of CW lasers, or the radiant exposure of pulsed lasers, may be compared directly to the MPE for classification.

3.2.9 Near UV and Mid IR (0.302 - 0.4 μm and 1.4 - 4.0 μm). Optical viewing devices may transmit and concentrate laser energy for some wavelengths in the near-ultraviolet and middle infrared. However, for these wavelengths, the hazard is to the anterior segment of the eye rather than to the retina. When optically aided viewing conditions are used to classify these lasers, a higher hazard class may result.

3.3 Evaluation of Personnel Injury Hazards.

3.3.1 General. Control measures necessary for outdoor operations rely heavily on a complete hazard evaluation of the laser system, rather than just the laser hazard class. The hazards vary greatly depending on the operating conditions and the proximity of individuals to the laser and to the laser beam path. Measurement of beam parameters such as divergence is often required since manufacturer's specifications are based on performance rather than safety (see Appendix D). A laser operating with increased power or energy per pulse, or a smaller beam divergence, could exceed the specified performance; therefore, the laser hazards would be increased.

Many diode laser systems are extended sources. Measuring the apparent source size (which is usually not provided by the manufacturer) is difficult and underestimation of the hazards could result from an inaccurate determination. Considering the laser as a small source will result in a conservative hazard analysis.

A hazard evaluation shall be performed for lasers exceeding Class 3R. As an example, see Appendix I for instruction on preparing a hazard evaluation report for a military system used on an international laser range. A hazard evaluation should be performed on invisible Class 3R lasers before they are intentionally pointed at personnel, which should only be permitted during a controlled test or exercise. Hazards from visible lasers should be considered,

especially if they are used outdoors at night in ways that could interfere with persons operating vehicles/ aircraft or performing other critical tasks.

3.3.2 Nominal Ocular Hazard Distance. The NOHD of a laser is determined from the relevant parameters of the laser system, i.e., power, beam diameter, divergence, and pulse characteristics (see Examples 2-5, Appendix B). When the laser beam is directed into a backstop, such as a hill or other opaque target that has sufficient size as to encompass the required buffer areas, the effective NOHD does not extend beyond this backstop. An example of NOHD calculation is provided in Example 7, Appendix B.

The potential use of optical viewing aids by persons near ground level and within the laser beam shall be considered. The NOHD-M is defined so as to prevent hazardous exposure of personnel potentially using optical viewing aids to view the source of laser energy, and when the use of optical viewing aids poses a significant risk, the LSO shall consider the NOHD-M when establishing a controlled area. Optically aided viewing by persons in the beam within aircraft is not usually considered unless there is specific information that such exposure might occur. The LSO has the authority to determine whether persons on the ground, who could potentially be using optical viewing aids, are likely to be injured by laser radiation.

3.3.3 Nominal Hazard Zone. The NHZ encompasses the portion of the laser beam where the level exceeds the MPE. The NHZ may extend from the laser transmitter to the laser backstop including any buffer areas, and any potentially hazardous specular or diffuse reflections (see Figures B3, B4 and B8, and Example 8, Appendix B).

3.3.4 Specular Reflection NOHD. A specular reflection introduces little distortion into the reflected beam. Not all surfaces that produce specular reflections look mirror-like. For example, a flat-bladed screwdriver looks diffuse but is mirror-like for far infrared wavelengths. The NOHD from a specular target depends on several factors (see Figure 2 and Figure B4, Appendix B). These include:

- (1) the polarization of the laser
- (2) distance from the laser to the reflector
- (3) the size of the reflector
- (4) the composition of the reflector material
- (5) the surface flatness of the material

(6) the angle at which the direct beam strikes the reflector material

When these factors are unknown, a worst-case estimate will usually result in a conservative NHZ. Specular reflectors that produce a distorted image when viewed produce a hazard only within the immediate vicinity of the reflector (see Figure 2, and Examples 12 and 13, and Figure B3, Appendix B).

3.3.5 Eye Protection. The optical density (OD) necessary for protection from a laser beam depends on the minimum approach distance of the laser, since the irradiance and radiant exposure decrease with distance. A higher OD is necessary if individuals are using optical viewing aids since these optical viewing devices effectively move the viewer closer to the laser transmitter (see Example 4, Appendix B).

Curved lenses used for eye protection outdoors will help reduce laser exposure of other personnel due to reflections of the laser beam from the lens surface. When eye protection is used for laser pulses lasting less than 1 ns, contact the eyewear manufacturer for information on possible saturable absorption (see Section 4, ANSI Z136.1).

3.3.6 Buffer Zones. The pointing accuracy of the laser system directly determines the size of the buffer zone. A buffer angle around the target area consists of the beam divergence of the laser plus an additional angle that would preclude any reasonable chance of the beam shifting out of the buffer zone. It is usually assigned a value 5 times the worst-case pointing inaccuracy.

3.3.7 Inclement Weather. During periods of inclement weather, additional hazards may exist. During rain or snow, diffuse and specular reflection from the raindrops or snowflakes could be hazardous to personnel located within 1 m of the laser beam path. Water or ice on surfaces or optical components illuminated by laser beams could redirect the laser beam creating hazardous exposures to individuals not exposed to the laser beam during dry weather conditions. Electrical hazards may also be created when rain or snow dampens electrical connections.

3.4 Visual Interference Hazards.

When visible lasers are employed, the impact from secondary visual effects on individuals performing critical tasks shall be considered. These effects include dazzle, startle, glare, flashblindness, or other visual impairment. These tasks include persons operating heavy equipment or machinery, driving a motor vehicle, flying an aircraft or performing other safety related functions. These effects are most

severe during reduced ambient illumination (night). Although these visual effects do occur in daytime at much higher exposure levels, the guidelines for visual interference zones and visual interference levels in this standard are designed for individuals exposed during periods of reduced ambient lighting.

3.4.1 Visual Interference Zones. For navigable airspace, the critical zone and laser-free zone are specified in Federal Aviation Administration (FAA) Order 7400.2 (see Figures 4, 5, and 6, and 4.6.2 for additional details). The local FAA office has the option of instituting a sensitive zone. The LSO shall be aware of the location of these FAA defined zones. The LSO should also establish the size and position of any other areas or zones that should be classified as critical or sensitive. Assignment of zones depends on the difficulty of the expected tasks and the consequences of the laser beam producing an error in the performance of those tasks.

3.4.2 Protection Distance. The same formula for computing NOHD may be used by substituting the visual interference levels for the MPE (see Appendix B, and Table 5). Appropriate protective mechanisms shall be employed if the laser beam intercepts a visual interference zone within the corresponding protection distance.

4. Control Measures

4.1 General.

Control measures, commensurate with the hazard, shall be devised to reduce the possibility of exposure of the eyes or skin to hazardous levels of laser radiation and to mitigate indirect hazards due to visual interference effects. These measures also include other hazards associated with the operation of laser devices during operation and maintenance. The LSO shall have the authority to monitor and enforce the control of the laser hazards and to effect a knowledgeable hazard evaluation and surveillance of the appropriate control measures. The detailed analysis of the NOHD should be made available to personnel potentially affected by the laser beam.

4.2 Controls for Laser Types.

4.2.1 Demonstration Products. Displays incorporating visible laser beams of any hazard class that enter a volume of airspace that has been designated as a particular flight hazard zone shall have an adequate system of controls if the effective irradiance levels exceed the corresponding visual interference level. A redundant system of both

electronic and visual observers may be required to ensure adequate control for displays that remain on for several hours, or are operated in heavy air traffic areas (see Appendices E and F).

NOTE: Safety observers have been found reliable in detecting aircraft at night within about 3 miles ground distance in populated areas. Safety observers may be reliable for detecting aircraft farther in semi-populated areas, and at much greater distances in remote locations where city lights are not encountered.

4.2.2 Scientific/Research Lasers. Lasers, such as LIDAR or laser tracking systems, often have beams that exceed the MPE at locations far from the laser site. Scientific and research lasers utilizing uninterminated beams may also constitute a hazard to aircraft or orbiting spacecraft. Operators of lasers that have a divergence less than $10 \mu\text{rad}$, or that exceed a peak irradiance greater than 1 mW cm^{-2} above 18 km (60,000 feet) in altitude above sea level, should contact U.S. Space Command regarding "Laser Clearinghouse" screening. Space Command will then advise the laser operator if any potential adverse effects on orbiting satellites are present, and provide operating conditions to mitigate these effects (see Appendix A).

Operating characteristics of these lasers are widely varying. Some are extremely powerful or have extremely small divergence. Control systems other than safety observers are often necessary since the hazards may extend many kilometers from the laser source. A system of electronic monitoring or safety observers may be necessary to prevent unsafe exposure levels along the full extent of the hazardous beam path (see Appendix F).

The regional FAA office should be contacted for a determination on the activity prior to operation, to ensure that the laser beam will not interfere with FAA flight operations. A letter of non-objection should be obtained from the FAA before operations begin (see Appendix A for sample letters).

4.2.3 Unattended Lasers. Laser systems intended for unattended operation such as infrared surveillance systems or autonomous systems, when possible, should be Class 1 or have a reliable shutdown mechanism to prevent exposure above Class 1. Higher class laser systems may be acceptable if the applicable hazard zones (NHZ, CFZ, LFZ, etc.) of the system are located in areas that are only accessible by appropriately trained personnel.

4.2.4 Low-Power Visible Lasers. Low power visible lasers shall not be intentionally misused for the purpose of causing visual interference. Visual

interference with critical tasks by low-power visible lasers (Class 3R or less) is possible, if they are intentionally used at dusk or at night, near roads or airports. Control measures for construction lasers are not required since these lasers are limited to hazard Class 3R for visible lasers ($0.4 - 0.7 \mu\text{m}$), and hazard Class 1 for other lasers. Construction lasers are not often used at night and would not be expected to create a direct or indirect hazard when operated by a qualified operator and when used as intended. Occupational Safety and Health Administration (OSHA) regulations require authorized construction laser operators to carry proof of qualification to operate the laser (29 CFR 1926.54).

4.2.5 Direct Fire Simulators. Small arms simulators (pistols, rifles and machine guns, etc.) used in force-on-force exercises, or in “laser-tag” products, should be Class 1 based on a 10 s exposure ($\text{MPE} < 1 \text{ mW cm}^{-2}$ for CW visible lasers). If all participants have received specialized training, weapon simulators shall be limited to Class 3R or below unless, under normal use, exposure of any participant is lower than the MPE. Weapon simulators with an output greater than twice the Class 3R AEL should not be used in force-on-force exercises in any case. Operation of laser weapon simulators above Class 1 (based on T_{max} of 10 s) shall be approved for the application and be confined to a designated training area. Approval shall be by the Technical Laser System Safety Authority for the specific military or law enforcement department.

4.2.6 Operator Controlled Lasers. Class 3B and Class 4 lasers that have a maximum NOHD for unaided viewing of about 100 m or less, may be operated outside of a laser-controlled area. This operation is only permitted when the operator has adequate laser safety training, has the capability of ceasing laser operation before potentially hazardous situations arise, and takes full responsibility for the safety of personnel who may enter the laser beam (LSO duties). Lasers that exceed an NOHD of about 100 m should only be used with specific predetermined controls and safeguards in place, such as following an SOP in a laser controlled area. As a minimum for such lasers, a separate safety observer should be available when the NOHD exceeds 100 m.

The NOHD for optically aided viewing from such devices could approach 700 m. The operator shall have a clear view of the beam path out to the aided NOHD, and shall be able to control access to the buffer area. The beam should be terminated into a backstop. The beam shall be kept from entering navigable airspace within the NOHD, or any visual interference zone at levels above the corresponding

visual interference level. In addition, the operator shall be aware when rotary winged aircraft could intercept the laser beam.

4.2.7 Airborne Lasers. The use of lasers on airborne platforms presents unique situations that shall be analyzed and mitigated if necessary. There is a potential for illumination of other aircraft as well as observers on the ground.

4.2.7.1 Air-to-Air Controls. Controls that may be effective in preventing air-to-air exposure include the use of Traffic Collision Avoidance Systems (TCAS), establishing control of the airspace within the area of laser operations, and providing a method of shutting down the laser or altering its output if the pilot or safety observer detects an aircraft on a potential intercept course with the beam (see Appendix F).

4.2.7.2 Air-to-Ground Controls. When determining the need for appropriate controls it is necessary to consider all potential exposure circumstances, such as aided viewing or multiple passes over a fixed point. One effective method of controlling exposure to persons on the ground is the use of precision altimetry that compares altitude to the NOHD for the laser in use. If the altitude registers as being below the NOHD the laser is automatically shut down or its output altered to reduce the NOHD. This will compensate for changes in ground contour without having to make changes in aircraft altitude.

Other methods that are effective are the use of variable laser output parameters, such as divergence, scan rate and energy, or alteration of the aircraft altitude or relative ground speed.

By reviewing the topography of the operations area and population density, as well as the aircraft and laser operations requirements, a suitable plan can be formulated in order to ensure the safety of observers on the ground. This is not meant to be a comprehensive review of all of the controls that may be effective as each operation is unique and requires individual consideration. In some instances it may not be possible to eliminate the hazard on the ground. In this case a detailed risk analysis should be done to evaluate whether the residual risk is acceptable.

4.2.8 Unmanned Aerial Vehicles (UAVs). UAVs present some unique safety concerns when fitted with laser devices. This is of increasing concern as the use of UAVs expands beyond the military and moves into law enforcement and commercial applications. When fitted with laser devices that have the potential to harm personnel or interfere with flight operations in navigable airspace, consideration shall be given to

the inclusion of control measures in the system design and/or operating instructions. Examples of control measures include automatic laser shut off if communication with the UAV is lost, or manual overrides of autonomous operation.

NOTE: Due to their unique mission requirements these types of control measures may not be appropriate for military operations.

4.2.9 Other Laser Applications. Lasers are used in a wide variety of other outdoor applications, including ground-to-air, ground-to-satellite, satellite-to-submarine, surface-to-submarine, and ship-to-ship. Beams directed into airspace may require coordination with FAA and possibly the U.S. Space Command Laser Clearinghouse. Visual effects should be considered for visible lasers used at night. Care should be used to avoid interference with military training exercises.

4.3 General Product Performance Requirements.

Users who are purchasing systems for use outdoors shall ensure that the system has adequate safety features. Systems that already meet the Federal Laser Standard will usually meet the following guidelines, except possibly those contained in 4.3.4. Guidance is provided by this section primarily for those systems not in full compliance with the Federal Laser Standard.

4.3.1 General. Lasers that have a DoD exemption or variance from the Federal Laser Standard shall comply with all the federal performance requirements that do not restrict operational requirements. Section 10 provides performance guidance for DoD laser systems when the exemption to the Federal Laser Standard applies.

4.3.2 Labeling. When an exemption or variance is obtained from FDA/CDRH, a label shall be placed on the device indicating the exemption or variance number. All other lasers intended for outdoor use shall have the certification label, as applicable, required by 21 CFR 1010.2 (see 4.3.4).

4.3.2.1 Identification Label. Every laser product shall be provided with a tag or label permanently affixed to the device housing so that it is readily accessible for viewing. This tag or label shall contain the full name and address of the manufacturer, the laser model, serial number, and should contain the month and year of manufacture.

4.3.2.2 Laser Warning Labels. Laser warning labels containing the starburst logotype symbol shall be placed on all lasers except Class 1. They shall

state whether the laser beam is visible or invisible, the output power or energy per pulse, the pulse characteristics and wavelength(s), and provide clear instructions to preclude laser injury. Examples of warning labels are provided in Figures 7a and 7b, and Figure A1, Appendix A (see ANSI Z136.1 for more examples).

An advisory protective housing label shall be required on removable non-interlocked panels that allow access to hazardous levels of laser radiation.

4.3.2.3 Aperture Label. Class 2 through Class 4 lasers shall have the laser exit port clearly indicated with a label. The label should state, “laser aperture”, “laser radiation is emitted from this aperture,” “laser light is emitted from this aperture”(for visible lasers), or similar wording (see 4.3.4).

4.3.3 Engineering Controls. The following engineering controls apply to Class 3B and Class 4 lasers with open beams, unless otherwise indicated as in 4.3.3.1 and 4.3.3.4.

4.3.3.1 Location of Controls. Each laser product (all hazard classes) shall have operational and adjustment controls placed so that human exposure to laser radiation at a level above the applicable MPE is unnecessary for the operation or adjustment of such controls.

4.3.3.2 Interlocks. Interlocked protective housings shall be provided for all hazard classes, to protect personnel from high voltage sources and unintended access to laser and collateral radiation in excess of the applicable MPE during operation or maintenance. Audible or visual indication of interlock defeat shall be provided. Interlocks shall return to their normal operation when the access cover or door is replaced. When laser radiation exceeding the ANSI Z136.1 Class 1 AEL is accessible when the cover is removed, an indication should be readily visible while wearing suitable laser protective eyewear (see 4.3.3.5).

4.3.3.3 Remote Interlock Connector. Class 4 lasers shall be provided with a readily available remote interlock capability. The interlock connector facilitates electrical connections to an emergency master disconnecting interlock, or to a control room, or area interlock as may be required for a Class 4 controlled area. Once disconnected, the system shall not automatically reactivate without an intentional reset. When the terminals of the connector are open circuited, the accessible laser radiation shall not exceed the appropriate MPE levels.

4.3.3.4 Emission Indicators. At least one emission indicator shall be used for Class 3B and Class 4 lasers. A laser-arming indicator is used to indicate that the laser is prepared to fire, and a separate firing indicator should be provided to inform the laser operator when higher-power Class 3B and Class 4 lasers are emitting. An indication shall be visible to the operator whenever a Class 3B, Class 4, or an invisible Class 3R laser is emitting. For some lasers, one indicator may serve both functions. This emission indicator(s) shall be visible through required protective eyewear.

NOTE: The laser-arming indicator may satisfy the Federal Laser Standard's requirement for an emission indicator delay in Class 3B or Class 4 laser systems 21 CFR 1040.10(f)(5)(ii) (2003). The laser-firing indicator can satisfy the federal requirement for an emission indicator for Class 2 or Class 3a (3R) laser systems.

4.3.3.5 Exit Port Cover. When an exit port cover is used, the exit port cover shall prevent access to laser radiation greater than the ANSI Z136.1 Class 1 AEL. When the cover serves as the required beam attenuator, the cover should clearly show when it is in place (SAFE) or open and shall continue to perform its function during intended use. A beam attenuator that satisfies the Federal Laser Standard is acceptable for this requirement.

4.3.3.6 Viewing Ports (Windows). Viewing ports and display screens that permit a person to view the laser beam or target area shall attenuate the laser radiation below the applicable MPE at the person's location. This includes aiming optics.

4.3.3.7 Optical Sights. When magnifying optics are used to aim the laser beam, they should include a built-in laser safety filter that protects the operator from all hazardous reflections from objects or targets in the beam path. It is not necessary to filter optics of lower-power Class 3B lasers when a hazardous reflected beam is unlikely. Aiming optics that are intended for use at night and employ a reticle should have sufficient reticle illumination.

4.3.3.8 Scanning Beams. Scanning laser products shall include a feature that prevents laser emission exceeding the AEL of the class of the product upon failure of any component. If the scanned laser radiation is less than 5 times the MPE, this feature shall prevent personnel exposure exceeding 5 times the MPE in case of a product failure that results in a reduction of scan amplitude or velocity.

4.3.4 Safety Performance Considerations. When hazardous beams are used outdoors, personnel not directly associated with the laser activity could be

potentially exposed to laser energy. Exposure of personnel shall be kept below the MPE. Distance is often used to minimize exposure in an outdoor environment. Any modification of the laser system output characteristics after evaluation could increase the exposure hazard.

To minimize exposure, it is therefore necessary to inform personnel of the potential locations of hazardous laser energy, and to provide a clear indication when, and from where, the laser is actually operating. Specific safety features shall preclude unintentional personnel exposure within a laser beam that exceeds the MPE or an appropriate interference level.

The following recommendations are an extension of the requirements of the Federal Laser Standard and ANSI Z136.1. As such, the safety features of this section may be added or tailored for a specific application if the LSO or user deems them necessary and appropriate.

4.3.4.1 Laser Firing Switch. The laser firing trigger or switch should be clearly identified and physically protected to prevent accidental activation (protected switch or "guarded" switch).

4.3.4.2 Unintentional Output. Unintentional laser output shall not result in a potential exposure that exceeds the MPE. The laser system should be designed to preclude unintentional self-oscillation, mode locking, double pulsing, unwanted modes, or misdirected beams. Lasers and associated optics should be designed without extraneous, external, secondary beams. Hot spots and collateral radiation should be minimized. Masking can be used to block extraneous beams.

4.3.4.3 Frequency Shifting. Laser systems that employ frequency shifting or harmonic multipliers to alter the fundamental output wavelength should reduce emission of unused wavelengths to below the MPE.

4.3.4.4 Location of Laser Beam. Permanently mounted laser systems should be installed in such a manner, that during intended use, unintentional exposure of any individual above the applicable MPE would be precluded. When the laser beam exceeds the MPE only for eye exposure, positioning of the beam in such a manner that the eyes will not be exposed near the laser exit port (even if laser eye protection is normally worn) when a person is either sitting or standing will reduce the risk of unintentional and unprotected exposure. Exposure to higher-power Class 3B and Class 4 lasers near the

laser exit port may exceed the MPE by 25 times or more, which could result in serious eye injury.

Scanning laser products, including mirror balls, should include a feature that prevents exposure to laser emission levels exceeding the MPE. This feature should also prevent laser emission exceeding any applicable visual interference level. This feature is not required for systems that normally switch between scanning and static beams, but control measures based on the most hazardous exposure condition should be used.

4.3.4.5 Consistent Output. The operating characteristics of the laser beam should be predictable since the hazard analysis is based on the laser's operating characteristics. A change in the designation or model number of the laser product should be used to indicate changes in performance that increases the NOHD or optical radiation hazards, of an existing system.

4.3.4.6 Shutters. An electrically triggered shutter to block the beam could be used as an alternative to interrupting power to the laser by a remote interlock connector. When used, shutters should be firmly attached to the laser system to completely block the laser output and be able to withstand any incident laser energy without failure. Shutters shall be designed such that the shutter remains closed when power is removed. After a remote interlock has shuttered a Class 4 beam, manual action shall be required to allow resumption of the emission of accessible laser energy (see 4.3.3.3).

4.3.4.7 Beam Masks. Beam masks may be used to limit the direction of spatial beam propagation. Beam masking can be accomplished with either hardware (beam blocks) or software.

4.4 Control of Higher-Power Class 3B and Class 4 Laser Beams near the Ground.

4.4.1 General. These beams include all those where access is possible from any ground-based structure within the applicable protection distance. Required control measures are dependent on the hazard zones in which the laser is used, the laser characteristics, and the specific environment in which the laser is used. Hazards include effects of laser beams other than those causing eye or skin injury. These hazards include transient visual effects, such as glare, flashblindness, dazzle, and afterimage, caused by unexpected exposure to bright light and the startle response that may result.

4.4.2 Standard Operating Procedures (SOPs).

Control measures devised to reduce the possibility of exposure of the eye and skin to hazardous levels of laser radiation and to other hazards associated with the operation of laser devices shall be incorporated into a standard operating procedure (SOP). A sample SOP is provided in Appendix A.

4.4.3 Nominal Hazard Zone (NHZ). Unprotected personnel shall be excluded from the entire NHZ through the use of acceptable control measures, such as positive control of the site by the laser operator, posting a guard, use of physical barriers, or through electronic monitoring. The NHZ may also be controlled by directly observing the entire region affected, establishing or using restricted regions. Safety observers may be used as a control measure, provided they have clear visual access to the region affected, and a direct means of terminating laser emission (see 5.2.6).

The NHZ includes all potential beam paths and areas near the laser where hazardous reflections are possible. It is determined in length by either the NOHD or the distance to a suitable laser backstop. The applicable buffer zones and the potential for hazardous diffuse or specular reflections from objects in the beam path determine the extent of the NHZ (see Figures 1, 2 and 3).

4.4.4 Laser Operation at a Site. Generally, higher-power Class 3B and Class 4 lasers shall be operated in a controlled area (a laser range with controlled access and a site LSO, see Figure 3). However, lasers that have a maximum NOHD of about 100 m for the unaided eye may be used outside a controlled area, provided the operator has had specialized training on laser hazards (see 4.2.6 and 5.2.4). The following protective measures are for operation of Class 3B and Class 4 lasers in a controlled area (e.g., a military laser range).

4.4.4.1 Restricted Access. The NHZ should be kept free of personnel by acceptable means (such as fences) when the NHZ is so extensive that entry cannot be controlled by visual observation. Entrance roads should be blocked with a temporary warning sign during actual laser firing operations (see Figure 8a). Guards should be posted at access points to prevent entry into the NHZ if it normally has public access. Guards should maintain communication with the laser control center (see 4.4.4.8).

4.4.4.2 Warning Signs. Warning signs should surround the laser-controlled area. A permanent sign should be present that states that laser use is permitted in this area, in addition to temporary

warning signs (see Figure 8b). In place of temporary signs, a permanent warning sign could be fitted with a warning light, a moveable or replaceable panel, or some other modifiable feature that indicates when the laser controlled area is currently in use.

4.4.4.3 Diffuse Reflection Hazards. When unprotected personnel, located near the exit port of a Class 4 laser, could be exposed to reflected laser energy above the MPE, the laser beam shall be kept free of any targets that would produce a hazardous diffuse reflection (see Tables 7 and 8).

4.4.4.4 Skin Hazards. Unprotected personnel shall not be permitted within the skin hazard distance of the direct or reflected beam from a Class 4 laser.

4.4.4.5 Buffer Zone. The target area and buffer zone around the target should be cleared of specular surfaces. If certain specular surfaces cannot be removed from the area due to training or testing requirements, the entire NHZ from the potential reflectors shall be contained in a controlled area and in protected airspace. This area shall be kept free of unprotected personnel through warning signs, barriers, and also guards, if necessary. In addition, visual observation of the buffer zone should be performed prior to live laser operations.

4.4.4.6 Laser Eye Protection. Laser eye protection should be worn by individuals inside the NHZ that provide an adequate OD at the correct wavelength at their work site. Eyewear should have curved lenses to reduce specular reflection hazards, and be selected for high visual transmittance.

Laser eye protection with curved lenses will usually limit hazardous specular reflections to within 10 m of the wearer. Otherwise, hazardous specular reflections from the eyewear could enter unprotected areas. When laser eye protection is used in reduced (night) illumination, consideration should be given that there is adequate visibility to allow performance of required tasks. Overall transmission of laser eye protection based on the photopic and scotopic visual response functions of the eye is often different.

4.4.4.7 Beam Backstop. A beam backstop shall have a non-specular surface and be opaque to laser radiation of the particular wavelength used. If located within the NHZ, it shall be large enough to encompass the entire laser beam and appropriate buffer area. The backstop may be either a terrain feature or a structure.

4.4.4.8 Communication Requirements. When the laser beam is hazardous at a distance where audible

communication is not practical, and persons are in the target area, communication between the laser operator and personnel in the target area shall be required during laser operations. Electronic communication is preferred, but flags or signs are a less desirable alternative.

4.5 Control of Laser Beams in Airspace.

Safety observers are discussed and laser safety methodology is addressed in Appendix E, and aircraft detection methods are contained in Appendix F.

4.5.1 FAA and FDA/CDRH Coordination. Except for military controlled airspace, a letter of non-objection should be obtained from the FAA before Class 3B or Class 4 lasers are operated in navigable airspace. Class 3B and Class 4 laser beams operated in airspace for entertainment or demonstration *require* an FDA/CDRH variance and an FAA aeronautical study. For other Class 3B and Class 4 lasers, an aeronautical study *should* be requested from the FAA before these lasers are used in navigable airspace.

4.5.2 Control Room. A control room is recommended for stationary use of Class 4 laser beams that are directed into airspace. Access to the laser should be strictly controlled by door locks, door interlocks, beam shields, and/or beam enclosures. When door interlocks control the entrance, the system shall not be automatically reactivated once the door is closed. Positive action by the authorized laser operator shall be required to reactivate the system.

The control room should be constructed so that the direct or a specularly reflected beam cannot expose persons within the room. Eye protection shall be available for all persons in the control room to provide protection from the direct beam. No one without laser safety training shall be allowed in the control room during operation of the laser. A shut-off switch shall be available to terminate the laser beam instantly. Communication shall be maintained with safety observers monitoring airspace.

4.5.3 Flight Zones. Airspace has been designated as normal flight zones, sensitive flight zones, critical flight zones, and laser-free zones, where visible laser beams may interfere with a pilot's vision, even if the MPE is not exceeded. These airspace zones correspond to the visual interference zones outlined in section 4.6. The normal flight zone comprises all airspace that may contain an aircraft and is not included in any of the other visual interference zones. Figures 4-6 illustrate these visual interference zones as applied to aircraft.

4.5.4 Tracking of Vehicles. Aircraft or ground vehicles shall never be tracked, either manually or automatically, with a potentially hazardous laser beam, except as a part of a controlled operation. Laser beams that exceed the MPE pose a potential for causing eye injury; however, laser irradiances less than the MPE may cause secondary hazards due to interference with visual tasks during periods of low ambient lighting (night). Therefore, illuminating an aircraft with a beam that either exceeds the MPE, or exceeds a visual interference level within the corresponding visual interference zone (at night), can create either a direct eye hazard or indirect hazards.

4.5.5 Military Operations. Airspace over and near military posts and bases may have a high density of fixed-wing and/or rotorcraft activity. Laser beams above the critical level or above the MPE shall not be directed into Special Use Airspace or Military Training Routes without coordination with the appropriate military authority that has jurisdiction over that airspace. A safety observer should not be relied upon to spot aircraft in these areas since the observer may not easily see these types of aircraft. Military representatives to the FAA, located at all of the FAA regional offices, should be contacted for assistance in these matters.

4.5.6 Control of Navigable Airspace. Lasers with beam irradiances less than the MPE, but exceeding the sensitive level or critical level may be operated in the sensitive zone or critical zone, respectively, if adequate means are used to prevent aircraft from entering the beam path. Electronic means (accepted by the FAA during an aeronautical study) is the preferred solution, although safety observers may be used to provide such prevention for short-duration operations (less than 1 hour, see Appendix F).

Any affected Air Traffic Control (ATC) facility should be able to directly communicate with the authorized laser operator to terminate the laser beam when these levels are exceeded. Permanent laser sites that may pose a hazard to air navigation should be annotated in the Airport Facility Directory and may be included on the Aeronautical Visual Flight Rules (VFR) sectionals.

A variety of electronic means may be used to monitor aircraft and automatically terminate the laser beam when aircraft could be exposed. The type of electronic monitoring should be accepted by the FAA before it is used to protect aircraft. When aircraft could be potentially exposed above the MPE, multiple methods for observing airspace are advisable. Appendix F describes some possible electronic monitoring methods.

4.6 Visual Interference.

4.6.1 General. Serious injury may result indirectly from laser exposure – especially visible laser exposure. The effects from visible laser exposure are most pronounced when a person is exposed at night or in a dark environment. All reasonable efforts shall be made to terminate laser beams that may interfere with unaided/aided vision or night vision devices though they may be beyond the NOHD if they cross roads, buildings, airspace or sea-lanes. Generally, a higher-power laser will produce a comparable effect during the daytime. However, during the daytime, the laser irradiance would need to approach the MPE for a laser to produce hazardous visual interference effects.

NOTE: Low-power lasers, such as laser pointers or laser scopes for rifles, can produce visual interference at dusk or night. Low-power laser products should only be used by responsible individuals and not provided to children as toys. The indiscriminate use of laser rifle sights or laser pointers to illuminate police or other individuals has been considered assault in some districts. Illuminating vehicles at night could cause an accident (see 4.2.4).

4.6.2 Flight Zones. In addition to retinal hazards, particular zones of critical activity involving tasks that would create safety problems from dazzle, startle, or distraction from visible laser beams can be established by the LSO during reduced ambient illumination (night operations). The beam from a visible laser shall not enter any visual interference zone when the irradiance is greater than the corresponding visual interference level unless adequate protective means are employed to prevent personnel exposure.

Figures 4-6 describe the zones established for aircraft in FAA Order 7400.2. Protective means shall be employed to ensure that personnel and pilots are not exposed above the applicable visual interference level. Redundant systems are advisable in locations noted for high-density air traffic (see Appendix E).

NOTE: Laser flight zones are intended to protect aircraft in flight and do not include locations inaccessible to airborne aircraft, such as within buildings or hangars.

4.6.2.1 Sensitive Zone. The sensitive zone encompasses the area on the ground or volume of airspace where exposure to intense visible beams would interfere with critical tasks, but does not jeopardize safety.

4.6.2.2 Critical Zone. The critical zone encompasses the area on the ground or volume of airspace where interference with critical visual tasks,

such as operating an automobile or aircraft at night, would jeopardize safety (see Figures 5 and 6).

4.6.2.3 Laser-Free Zone. When laser beams in this zone exceed the laser-free level, redundant layers of protective mechanisms are advisable since visual interference by a laser beam in this zone would be very serious (see Figures 4-6).

NOTE: The laser-free irradiance level could be 50,000 times below the corresponding MPE.

4.7 Aircraft Detection Methods.

Detection methods include the use of safety observers posted near the origin of the laser beam, gathering data from various types of radar, using data collected from FAA radar, using images from infrared camera systems, and receiving data transmitted directly from potentially exposed aircraft. See Appendix F for additional discussion of these methods.

5. Laser Safety Program Management and Training Requirements

5.1 General.

An LSO shall be designated for all circumstances of operation, maintenance, and service of a Class 3B or Class 4 laser or laser system. An LSO should be designated for invisible Class 3R lasers and laser systems that are intentionally pointed at personnel (such as direct-fire weapon simulators). When a laser is used outdoors, often multiple organizations are involved, such as the:

- (1) owner of the laser equipment
- (2) authorized laser operator
- (3) supervisor of the laser operators
- (4) owner of the property, or the one who is responsible for safety on the property, where the laser is located, e.g., laser range safety officer
- (5) one who is responsible for safety in airspace, or ground area, where the laser beams are located

5.2 Safety Organization.

5.2.1 Laser System Management Organization (LSMO). Managers (employer or system owner) shall establish and maintain an adequate laser hazard control program as described in ANSI Z136.1. Safety and training programs shall be required for all Class 3B and Class 4 lasers and laser systems. Managers of Class 3B and Class 4 lasers and laser systems shall establish an LSMO and shall designate

an LSO. The LSMO LSO is responsible for overall safety of the laser program and shall coordinate with all essential personnel and property owners where the system is located.

Safety and training programs should be required for Class 3R lasers and laser systems. Safety and training programs are not required or necessary for Class 1, or Class 2 lasers and laser systems. Managers should consider whether safety and training programs are required for their application of Class 1M and Class 2M lasers and laser systems, since these lasers may present a significant risk of injury under some circumstances.

5.2.2 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 with both the authority and the responsibility to monitor and enforce the control of laser hazards, and to effect the knowledgeable evaluation and control of laser hazards (see 1.3 for specific responsibilities).

5.2.3 Laser Safety Specialist. When the LSO does not have the knowledge or training to determine necessary laser control measures, the LSO may act on the recommendations of a laser safety specialist. The laser safety specialist has formal training or equivalent professional experience to calculate and determine laser hazards, and to recommend appropriate control measures. With this formal training, the LSO or authorized laser operator may also be a laser safety specialist.

5.2.4 Authorized Laser Operator. Operators of Class 3B and Class 4 outdoor lasers shall:

- (1) be appropriately trained in the safe use of the lasers they operate
- (2) follow SOPs for safe work practices to mitigate hazards to their fellow workers and the general public
- (3) direct the beam at a height and location to prevent hazardous exposure to personnel or occupied areas
- (4) have adequate knowledge of the operation and basic maintenance of the laser systems being used
- (5) have a general knowledge of laser bioeffects
- (6) have an understanding of the laser hazard evaluations for the on-site conditions

5.2.5 Personnel in the Target Area. Exposed personnel shall:

(1) have the capability of terminating laser emission when a hazardous condition is identified

(2) follow SOPs for safe work practices, to mitigate hazards to their fellow workers and the general public

(3) have a general knowledge of laser bioeffects

(4) have an understanding of the laser hazard evaluations for the on-site conditions

5.2.6 Safety Observer. Safety observers shall:

(1) have distant visual acuity corrected to 20/20, normal visual fields, no pathology of the eye

(2) have the capability and authority to terminate the laser emission when a hazardous condition is identified

(3) identify and report potential conflicts within visual detection range to the LSO

NOTE: The LSO should not rely solely on safety observers to detect aircraft when the effective irradiance exceeds the visual interference level beyond a 3 mile horizontal distance.

(4) take into account visual fatigue. The LSO shall provide for regular rotation, e.g., a 10-minute break for every hour of observation, or one hour of observing and then an hour off

(5) have an unobstructed view of the laser beam paths and buffer zones, or a view that overlaps with additional observers

See 11.2, SAE ARP 5535, for further information on requirements for Safety Observers.

5.3 Training.

Laser safety education and training commensurate with the hazards shall be provided to supervisors and users. The exact amount and depth of detail should be tailored to each situation. Generally, LSOs in a management capacity should receive training as outlined in ANSI Z136.1, Appendix D6. (Appendix G of this standard for training of Laser Workers, Laser Safety Specialists, Laser Systems Management Organization LSO, Site LSO, Laser Operator, Personnel in Target Area of Laser, and Safety Observers.)

6. Medical Examinations and Surveillance

6.1 General.

Medical examinations and surveillance requirements for laser workers shall be in accordance with ANSI

Z136.1. Medical surveillance requirements have been limited to personnel who are clearly indicated to be at potential risk of injury from laser radiation.

6.2 Personnel Categories.

The personnel categories are based on potential risk. The categories are incidental personnel and laser personnel. The type of required examination is determined by the category (see ANSI Z136.1).

6.3 Reporting of Laser Accidents.

When an overexposure to laser radiation is suspected, the exposed individual should contact the LSO as soon as possible. Delay (of even hours) in receiving any available treatment for a laser overexposure could render the treatment ineffective.

Manufacturers of laser products, including producers of laser light shows and displays are required by FDA/CDRH to report accidental radiation occurrences to the FDA/ CDRH (see 21 CFR 1002.21). Therefore, involved personnel should report such occurrences through their supervisors or commanders so that the appropriate manufacturer or producer can be notified.

7. Non-Beam Hazards

7.1 General.

In addition to direct hazards to eye or skin associated with exposure to the laser beam, addressing other hazards associated with the use of lasers is also important, including non-beam hazards.

Non-beam hazards in some cases can be life threatening, e.g., electrocution or interruption of critical tasks. Consequently, the special considerations discussed in this section require use of control measures different from those discussed in section 4. Because of the diversity of these potential hazards, the LSO may employ safety/human factors, health physics, and/or industrial hygiene personnel to effect the hazard evaluations for special considerations.

Personnel hazards include electrical (shocks, burns, electrocution), physical (software/robotics commanding unsafe conditions), hazardous materials, confined space, exposure to electromagnetic radiation (radiofrequency, incoherent light), and ionizing radiation.

7.2 Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC).

EMI and EMC effects from the laser product and to the laser product should be determined and appropriate safeguards to preclude these effects should be incorporated into the product design. Laser products shall comply with appropriate Federal Communication Commission (FCC) regulations.

7.3 Ergonomics and Human Factors.

The system shall minimize musculo-skeletal stress to the installer and operator. Human factors considerations shall include lighted, calibrated reticules for target viewing and alignment, and display indicators and controls that are visible through laser eye protection.

7.4 Software/Robotic Control.

Computer software should not be solely relied upon to provide a safe working environment. Hardware stops and beam masks should be used when possible. When failure of software could create personnel hazards, it should be analyzed and validated to prevent unexpected failure. Robotics safety practices of ANSI R15 and OSHA Pub 8-1.3 should be followed. Safety practices to preclude robotics mechanical hazards may include the use of surface interlock mats, interlocked light curtains, or non-rigid walls or barriers.

8. Criteria for Exposures of Eye and Skin

8.1 General.

Maximum permissible exposure (MPE) values are below known injury levels. Exposure to levels approaching the MPE may be uncomfortable to view or feel upon the skin. Thus, it is good practice to maintain exposure levels well below the MPE level. The MPEs referred to in this standard are generally limited to an exposure duration less than 10 s. For intentional viewing of a laser beam for an exposure duration of more than 10 s, refer to ANSI Z136.1.

When visible lasers are used outdoors at night, secondary hazards due to the intense light may produce hazardous situations at levels below the MPEs. These additional hazards, addressed in this document as visual interference levels, are not covered in ANSI Z136.1.

8.2 MPE for Ocular Exposures.

The MPE (to prevent biological injury) for any laser beam and exposure condition are provided in Tables 5a and 5b (ocular exposure limits) in ANSI Z136.1. For convenience, Table 2 provides MPEs for common lasers used outdoors for typical exposure

durations. If differences are noted between Table 2 of this standard and Tables 5a and 5b of the ANSI Z136.1, the latter take precedence. The MPEs are listed in terms of irradiance or radiant exposure on the eye or skin. For small beam sizes, actual exposure levels are averaged over the limiting apertures listed in Table 3.

8.2.1 MPE for Repetitive Pulse Lasers. For repetitive pulse lasers, the MPE in terms of average power is lower than for a CW exposure when the repetition frequency is less than the critical PRF. Table 4 provides a conversion for most Q-switched, repetitive pulse lasers used outdoors. The MPE would need to be calculated for pulsed lasers that are not included in Table 4. For repeated exposures to laser beams, the MPE per pulse is determined from the lowest MPE based on the following three rules:

(1) The MPE per pulse is limited so that the exposure from any single pulse in the pulse train will not exceed the MPE. The limiting aperture is based on the duration of a single pulse (not limited by $t_{\min}$)

(2) The MPE is limited to the MPE for a CW exposure, based on average power for any exposure duration T up to $T_{\max}$ (see 8.2.3). The limiting aperture is based on T

(3) The MPE/pulse is limited to the single-pulse MPE multiplied by a correction factor for multiple pulses. The multiple pulse correction factor, C_p , is $n^{-0.25}$, where n is the number of pulses during the exposure. Pulses occurring within a time duration of $t_{\min}$ are considered as one pulse for this rule. The limiting aperture is based on the duration of a single pulse (≤ 0.25 s)

NOTE: Since pulses are defined as exposures lasting no more than 0.25 s, C_p does not usually apply for wavelengths between 1.5 μm and 1.8 μm since $t_{\min} > 0.25$ s. The pulse repetition frequency for which the MPEs based on rules 2 and 3 are equal is termed the critical PRF. For a 10 s (or shorter) exposure to a small Q-switched source, the critical PRF is 55 kHz for wavelengths between 0.4 μm and 1.05 μm , and 22 kHz for wavelengths between 1.05 μm and 1.4 μm . For unusual pulse structure, refer to Section 8, ANSI Z136.1. For UV and IR lasers, the critical PRF is generally much lower.

8.2.2 Extended Sources. The lasers associated with most exposures encountered in an outdoor environment would appear as a small source and would produce a small retinal image for visible and near infrared lasers. However, viewing diffuse reflections, or directly viewing some laser projection systems from within the beam at a close viewing distance, may produce larger retinal images, and the source would appear as an extended source.

Except for lengthy exposures to laser wavelengths less than approximately $0.6\ \mu\text{m}$, the MPE is based on thermal effects, and extended sources have a higher thermal MPE in terms of corneal exposure due to a correction factor, C_E . Extended sources have an apparent visual angle greater than $\alpha_{\min}$, defined as 1.5 mrad (see 9.5).

For a larger source, a correction factor C_E is applied to the thermal MPE. This correction is linear with source diameter for extended sources less than $\alpha_{\max}$ (100 mrad). The factor is defined as follows:

$$C_E = \alpha/\alpha_{\min} \text{ for } \alpha_{\min} < \alpha < \alpha_{\max}$$

$$C_E = \alpha^2/(\alpha_{\min} \cdot \alpha_{\max}) \text{ for } \alpha > \alpha_{\max}$$

Thus, laser energy striking the cornea from those portions of a source that are outside of an angle greater than $\alpha_{\max}$ do not further contribute to retinal injury, and may be ignored.

For rectangular or elliptical images, the arithmetic mean of the two dimensions should be used for determining C_E . Dimensions less than $\alpha_{\min}$ should be considered as $\alpha_{\min}$ and dimensions larger than $\alpha_{\max}$ should be considered as $\alpha_{\max}$.

8.2.3 Exposure Duration. For a single-pulse laser, the exposure duration is the duration of a single pulse. For a CW or repetitive pulse laser, the exposure duration is the maximum time of anticipated exposure. For unintentional exposure, a maximum exposure duration of 0.25 s is used for visible lasers ($0.4 - 0.7\ \mu\text{m}$) producing a strong visual stimulus ($2.5\ \text{mW cm}^{-2}$) and a maximum exposure duration of 10 s is used for other lasers. Other exposure durations are used based upon equipment design and the exposure environment.

Aircraft exposure to a repetitive-pulse, Q-switched laser may be extremely short due the relative speed of the aircraft and a stationary laser beam; however, exposure to at least one laser pulse should always be considered (see 8.4).

For brief intentional, but intermittent, exposure to visible lasers, the exposure duration is also 10 s. The MPE for visible lasers operated in the sensitive and critical flight zones during daylight is also based on a 10 s exposure duration ($1\ \text{mW cm}^{-2}$). For a small-diameter laser beam, this level corresponds to $0.4\ \text{mW}$ through a 7 mm diameter measurement aperture.

The MPE for a visible scanning laser that has a scan failure event shall be based on an exposure duration that is equal to the maximum total reaction time (from scan failure to beam termination) of the

scanning safeguard system (see Example 22, Appendix B).

8.3 Visible Light Interference.

A hazard may result if an operator of machinery is dazzled or otherwise startled by a laser beam while performing a critical task.

8.3.1 Visual Interference Levels. It has been recognized that serious bodily injury may indirectly occur due to visible laser beams that are below the MPE when they affect the performance of critical tasks. Control measures based on visual impairment (instead of the MPE) are only applied for laser exposure during reduced ambient illumination. Unlike the MPE, no correction is made for extended sources. Three levels of laser visual interference are defined: sensitive, critical, and laser-free. These levels correspond to the zones described in section 4.6.2.

NOTE: In some instances, the MPE can be exceeded even when the visual interference level is not exceeded, such as for a short-pulsed visible laser with a very low duty cycle. Care shall be taken to ensure that personnel are not exposed above the MPE in these situations. When any calculated distance for the sensitive exposure distance, critical exposure distance, or laser-free exposure distance is shorter than the NOHD, these distances default to the NOHD. No reference should be made to a distance based on visual interference that is shorter than the NOHD.

8.3.2 Visual Interference Duration. The amount of visual interference that is caused by a laser beam depends on the duration of the effect. In most cases, however, the duration of an unintentional exposure cannot be accurately determined since the persons may be moving rapidly, e.g., operating motor vehicles or aircraft. The duration of the visual interference may be less than 0.25 s due to flight intercept geometry or equipment design. In this standard, visual interference is based on the effective irradiance for exposures exceeding 0.25 s and on effective radiant exposure for exposures less than 0.25 s (see Table 5).

8.3.3 Luminous Efficiency Function. Visual interference from a visible laser beam depends on the spectral sensitivity of the eye (see Appendix H). Visual interference levels are wavelength dependent and the eye is most sensitive in the wavelength band near $0.55\ \mu\text{m}$. The photopic luminous efficiency function, $V(\lambda)$, from Table 1 is applied to the actual irradiance to obtain the effective irradiance. The effective irradiance multiplied by 683 is the illuminance in lumens cm^{-2} .

8.4 Repetitive Pulse Lasers.

Repetitive pulse exposures are treated differently depending on whether exposure above the MPE is considered or visual effects are of concern. Multiple pulse exposure results in a lower MPE based on average power than a similar CW exposure (see Table 4). Visible light, pulsed at 8 to 16 pulses per second, should be avoided to prevent interference with the brain's alpha rhythms. Such interference could result in vertigo or other physiological damage to those who may be sensitive to stroboscopic effects, especially photosensitive epileptics. However, no multiple-pulse correction is used for repetitive pulse lasers for visual interference effects.

When the laser PRF is above the critical fusion frequency (CFF), the laser appears to be continuous rather than pulsed. The critical fusion frequency varies with ambient illumination, and a conservative approach should be followed for lasers with PRFs less than 70 Hz until more information is available. The MPE should always be computed for low repetition rate lasers since the MPE is often less than visual interference levels for these lasers. The MPE takes precedence when it is less than a particular visual interference level (the NOHD would then be greater than the visual interference distance).

8.5 MPE for Skin Exposure.

MPE values for skin exposure are listed in Table 6. The MPE for repetitive pulse lasers is the lower of the single-pulse and average-power MPEs. The correction factor C_p is not used for skin exposure.

8.6 Flight Geometry.

When an aircraft is involved, geometry of the flight path, speed of the aircraft and the direction and the inclination of the laser beam play major roles in determining actual exposures. The effective radiant exposure (the intercepted beam irradiance $\times$ the exposure duration), not simply the irradiance, determines the visual effect. Situations where extended exposure durations are possible shall be avoided, e.g. aligning a visible laser beam with an airport runway would be poor laser safety practice.

9. Measurements and Instrumentation

9.1 General.

Measurements are often required for laser systems designed for outdoor use. System parameters provided by manufacturers are usually performance based rather than based on the safe use of the laser.

A slightly smaller beam divergence or higher output power can increase the distances from an outdoor laser system within which protection is required. A laser safety specialist using instruments designed to accommodate the typical properties of the laser beam, i.e., spatial and temporal coherence, nonuniform irradiance pattern, and potentially high irradiance levels, should perform measurements, if any are deemed necessary (see Appendix D and ANSI Z136.4).

9.2 Detectors.

Laser radiation detectors allow the user to locate, measure, or calculate the incident laser radiation. Photoluminescent materials, such as detector cards, can be used to locate invisible laser beams, but are usually not recommended for radiometric measurements. Optical detectors can generally be divided into two major categories: thermal and quantum detectors.

9.2.1 Thermal Detectors. These detectors absorb laser radiation and convert the electromagnetic energy to thermal energy. Thermal sensors whose electrical outputs are measured and then correlated with the amount of incident radiation can monitor the resulting temperature increase. Two common types of thermal detectors are thermoelectric and pyroelectric detectors (see Example 2, Appendix B).

9.2.2 Quantum Detectors (also called Photodetectors). These detectors respond to individual photons by generating a current or voltage in an external circuit. Quantum detectors are characterized by high sensitivity, fast response, and a marked wavelength dependency.

9.3 Measurement Conditions.

9.3.1 Unaided viewing. The power or energy that can be transmitted through the measurement aperture is needed to compare with the Class 1 AEL for determination of the NOHD and protective eyewear requirements. The measurement aperture for unaided viewing is the same as the limiting aperture. Table 3 provides limiting apertures and measurement apertures as defined in ANSI Z136.1 for both unaided and optically aided viewing conditions.

Measurements for purposes of classification shall be performed at distances of 10 cm or more from the laser exit aperture and the classification shall be determined at the most hazardous position along the beam path. For lasers with an external beam waist in either or both dimensions, the measurement aperture

should be placed at the distance where the measured energy is maximized.

9.3.2 Optically Aided Viewing. The measurement aperture for optically aided viewing is determined by multiplying the limiting aperture by the magnifying power of any optical aid.

The MPE for optically aided viewing may be greater than the MPE for unaided viewing when viewing extended laser sources due to a larger value of C_E (see 9.5). For optically aided viewing, e.g., binoculars or telescope, the measurement aperture should be placed at the distance where the hazard is maximized, but no closer than 2 m from the laser exit aperture.

For extended source lasers with a small exit beam diameter, the most hazardous distance (and appropriate measurement distance) for optically aided viewing is near the location where the beam size approaches the size of the entrance aperture of the viewing optics, which may be significantly larger than the normal measurement distance of 2 m (see Example 3, Appendix B).

Since source size varies inversely with beam diameter, the source size may not be much larger at this distance than it is for unaided viewing, and the MPE at that location would not be increased by much from the value for unaided viewing. However, for large exit beam diameter, extended source lasers, the MPE may be increased by as much as the magnifying power of the viewing optics.

9.4 Pulsed Lasers.

When the pulse repetition frequency of a laser is less than the critical PRF, measurements of energy per pulse and PRF are required to complete the hazard analysis. The energy per pulse may be measured directly, computed from average power, or computed from peak power and pulse width.

9.5 Extended or Diffuse Sources.

The MPE for viewing a laser that has an extended apparent source, or produces a diffuse reflection with an extended source, is larger than that for a small source. This larger MPE may affect the NOHD or protective eyewear requirements for that laser. This is due to the size of the laser image created on the retina. A conservative approach is to assume no correction for source size. The size of the laser beam striking a diffuse target affects the hazard of the reflected beam if the viewer is close to the target.

Table 7 provides diffuse reflection information for CW lasers. Diffuse reflection information for pulsed lasers is contained in Table 8. The apparent angular

subtense at the viewer's location shall be larger than $\alpha_{\min}$ in order to apply a correction factor to the MPE. When optical viewing aids are employed, the source is magnified by the power of the optical system.

NOTE: Although a laser beam could be larger than the pupil (7 mm), looking into the beam will result in a small apparent source if the laser beam is collimated.

9.6 Optical Density of Protective Filters.

Measurement of optical density should only be attempted by a laser safety specialist under controlled laboratory conditions. It is not generally recommended that a laser user determine OD through measurement. It is better to consult the filter or eyewear manufacturer (see 4.6 of ANSI Z136.1).

NOTE: Although protective eyewear may provide an OD that is adequate for a laser, direct exposure by some Class 4 lasers having small beam diameters may damage or burn through the protective materials.

9.7 Polarization.

Optical polarization of the laser beam is not normally used when determining protection distances of a laser system. Although many lasers have unpolarized beams, measurements made with polarized laser beams can produce unexpected results for energy reflected off specular surfaces. Many lasers use Brewster windows, which polarize the output beam. The direction of polarization can be determined using a polarizing filter or by a separate Brewster window. To make the measurement, the filter or separate Brewster window is placed between the laser and detector. The polarization may be determined by rotating the filter until the detector reading is either a minimum or maximum.

9.8 Measurement Accuracy.

A 20 percent error in computing either irradiance or radiant exposure is acceptable since the exposure limits or visual interference levels do not represent a fine line between a hazardous and non-hazardous situation. However, a 10 percent error in computing beam diameter or divergence could produce a 20 percent error in irradiance or radiant exposure, e.g., overestimating the beam diameter by 10 percent can lead to a 20 percent underestimation of the beam irradiance.

9.9 Atmospheric Effects.

Scintillation and atmospheric effects can make measurements at a distance from a laser source difficult to interpret. Appendix C covers atmospheric effects.

9.10 Pointing Accuracy.

Pointing accuracy of a laser can be determined by considering the design of the system and the platform from which it will be used. For example, a rigidly mounted system will have a better pointing accuracy than a hand-held system.

9.11 Measurement Techniques.

Appendices B and D provide suggested examples of measurement techniques.

10. Special Requirements for U.S. Department of Defense Laser Systems

10.1 General.

The requirements in this section apply only to those laser systems that are developed for or sold to the U.S. Department of Defense (DoD) and have been exempted from the federal product performance requirements of the Federal Laser Standard. These lasers are developed as tactical or tactical-training systems, or have uses or parameters classified in the interest of national security. The requirements of this section may be used as guidance for other organizations having an exemption from the Federal Laser Standard.

The requirements contained in this section apply to all exempted laser systems offered for sale to the Department of Defense (the FDA/CDRH no longer issues variances based on exclusive use by DoD). The DoD exemption shall only be applied to laser systems after the manufacturer has received authorization from the DoD procuring activity in writing. Once the DoD exemption is applied to a laser system, the working system shall not be sold, loaned, or donated to organizations outside the Department of Defense. It may only be sold to non-DoD organizations if the laser system is destroyed beyond repair, or the laser system is brought into full compliance with the Federal Laser Standard. The requirements for DoD systems in this section are intended to replace those requirements in section 4.3 of this standard.

Deviations from the requirements of this section of the standard may be permitted by the appropriate military service agency when suitable alternate control measures are instituted.

10.2 Purchasing Authority.

U.S. DoD organizations purchasing laser equipment have the option of applying the DoD exemption from the Federal Laser Standard. Regardless of class or

exemption status, lasers manufactured for the DoD that are intended for use in combat, combat training or classified in the interest of national security, shall have approval for use by the appropriate military authority.

The DoD procurement office or purchasing agent determines whether a particular laser system meets the above criteria and whether an exempted laser system is desired. When the intended use of the laser device does not conflict with any of the federal product performance requirements, the DoD exemption is not necessary and therefore, the laser system is required to meet all the requirements of the Federal Laser Standard.

When modification of one or more of the federal requirements is necessary, the DoD exemption shall be applied if the system is to be procured by the DoD agency. The manufacturer should not request a variance from the Federal Laser Standard for devices that are eligible for the DoD exemption. When the DoD exemption is used, the manufacturer is exempted from the entire Federal Laser Standard; however, all portions of the Federal Laser Standard that do not conflict with the requirements of the DoD purchasing organization shall be met.

10.3 Hazard Evaluation.

All Class 3B and Class 4 lasers that are intended to use open beams, and all laser-based weapon simulators shall have a hazard evaluation by the appropriate military agency, regardless of whether the DoD exemption is used. This laser hazard evaluation may include additional or alternate safety requirements to this standard. The hazards from currently fielded tactical lasers and weapon simulators are discussed in Military Handbook 828.

10.4 Military Service Agencies.

Prior to the sale or use for any laser systems eligible for military exemption that are designed or intended for use outdoors, the appropriate agency within each service shall be contacted by either the purchasing agent or the laser manufacturer. The procuring activity shall request assistance, with sufficient lead-time, so that a hazard evaluation can be performed prior to testing or use by U.S. Government personnel or on U.S. Government property.

For the U.S. Army, contact the Laser/Optical Radiation Program of the U.S. Army Center for Health Promotion and Preventive Medicine, 5158 Blackhawk Road, Aberdeen Proving Ground, Maryland 21010-5403, telephone (410) 436-3932.