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*American National Standard for
Safe Use of Lasers Outdoors*



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American National Standard for Safe Use of Lasers Outdoors

**Secretariat
Laser Institute of America**

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**American
National
Standard**

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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 $\alpha_{\min}$).

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 I 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 (TEM₀₀).

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 μm (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 (J cm⁻² 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 μm (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_f). 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 μ 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 radian = 57.3 degrees; 2π radians = 360°.

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

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 ($J\text{ cm}^{-2}$).

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 μ m and 1.4 μ 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 $10\text{ }\mu\text{rad}$, 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 $0.6\text{ }\mu\text{m}$, 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 ($0.4 - 0.7\text{ }\mu\text{m}$) producing a strong visual stimulus (2.5 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 mW cm^{-2}). For a small-diameter laser beam, this level corresponds to 0.4 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 $0.55\text{ }\mu\text{m}$. 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.

For the U.S. Navy and Marine Corps, contact Code G-72 of the Dahlgren Division of the Naval Surface Warfare Center, 17320 Dahlgren Road, Dahlgren, Virginia 22448-5100, telephone (540) 653-1060. The Navy Laser Safety Review Board (LSRB) authorizes the conditions under which the equipment can be used.

For the U.S. Air Force, contact the Optical Radiation Branch of the Air Force Research Laboratories, 2650 Louis Bauer Drive, Brooks City Base, Texas 78235-5218, telephone (800) 473-3549.

10.5 Performance Criteria.

With the exception of 10.5.1, the following criteria apply only to Class 3B and Class 4 laser systems unless stated otherwise.

10.5.1 Labeling. All applicable labels shall be legible and readily accessible to view when the product is fully assembled for use. These labels shall also be installed in such a manner that viewing them does not require personnel exposure to laser radiation. When labels may compromise camouflage, muted colors appropriate to the camouflage paint scheme are acceptable. Information classified in the interest of national security may be omitted from labels. Multiple label requirements can be combined by the use of a single label whenever practical.

10.5.1.1 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 to view. This tag or label shall contain the full name and address of the manufacturer, the laser model, serial number, and the place, month, and year of manufacture. These may not be expressed in code.

10.5.1.2 Compliance Label. All lasers, regardless of hazard class, that meet the performance requirements of the Federal Laser Standard shall be labeled as such.

10.5.1.3 Exemption Label. Every laser product exempted under 76EL-01 DoD shall be provided with a tag or label permanently affixed to the device housing so that it is readily accessible to view. The label should contain one of the following statements (similar statements may be acceptable if approved by the appropriate military service agency):

CAUTION

This electronic product has been exempted from FDA radiation safety performance standards prescribed in Title 21, Code of Federal Regulations, Chapter I, Subchapter J, pursuant to Exemption No. 76EL-01 DOD issued on 26 July 1976. This product should not be used without adequate protective devices or procedures.

Products bearing this label shall only be used by persons performing official duties of the U.S. military, and shall not be sold or otherwise transferred to others.

10.5.1.4 Laser Warning Labels. All lasers except Class 1 require a warning label. The warning label shall include: NOHD, wavelength, maximum power or energy output, and the word “visible” or “invisible”. These parameters shall be approved by the appropriate military authority. Warning labels shall be located on the laser emitter and if remotely operated, near the fire control switch. Examples of warning labels are included in Figures 7a, 7b and A1. Refer to ANSI Z136.1, Section 4.7.5 for further details on labeling.

10.5.1.5 Laser Output Label. All lasers except Class 1 and Class 2 shall have a label notating the location of the emission port of the laser. Class 1 invisible lasers should have a label indicating the location of the emission port.

10.5.1.6 Interlock Label. When a Class 1, 1M, 2, 2M, or 3R laser system has a defeatable interlock that, when defeated, allows access to Class 3B or Class 4 emission levels, the following label shall be installed on or near the access panel:

DANGER

Hazardous laser radiation emitted when open and interlock defeated. Avoid eye or skin exposure to direct or scattered radiation.

10.5.2 Laser Fire Controls. The laser fire trigger or switch shall be clearly identified and shall be physically protected to prevent accidental activation. The switch shall be a protected positive action (“dead-man”) type requiring continuous operator intent to operate the laser. Laser activation circuitry for pulsed lasers shall be of a fail-safe design so that continual depression or short-circuiting of the fire control switch will not cause repeated emissions

unless necessary for performance of intended function(s).

When operational considerations preclude the use of a dead-man switch, a toggle switch may be used if adequate safeguards are provided to prevent long-term inadvertent laser operation, e.g., through watchdog timers and system logic switching.

All laser fire controls shall be located so that human exposure to laser radiation in excess of the appropriate MPE is unnecessary for the operation or adjustment of such controls.

10.5.3 Emission Indicator. All lasers except for Class 1, Class 1M, Class 2 and Class 2M shall be equipped with a laser emission indicator to inform the laser operator when the laser is actually emitting optical radiation. Additionally, a laser arming indicator shall be provided for lasers that can emit more than five times the Class 3R AEL to inform the laser operator when the laser is prepared to fire (armed). Power or mode control switches may serve as laser arming controls. These indicators shall be visible through required laser eye protection and shall not require human access to laser radiation in excess of the appropriate MPE.

10.5.4 Optical Sight Filters, Viewing Ports, and Display Screens. Lasers with viewing ports, viewing optics, or display screens having a magnification greater than 1.0 shall include a built-in laser safety filter that protects the operator from reflections or direct exposures from that type of laser system. For those systems with 1.0 or less magnification, such safety filters should be considered and may be required by the appropriate military service authority. Such filters should be permanent, should not significantly impair visibility, and should be marked with all applicable wavelength and optical density parameters. Alternative to wavelength and optical density, a code may be used as described in Tables 9 and 10 to indicate the level of protection.

10.5.5 Reticules. When aiming optics are necessary to direct the laser beam, they shall employ a reticule that can be viewed under any desired illumination condition and should not impair dark adaptation of the user's eyes. Calibrated reticules should be considered so that the laser operator can determine the proximity of the laser beam to target buffer zones. Alignment of the optics to the laser beam shall be considered a safety critical item.

10.5.6 Remote Control Systems. When a laser is operated remotely, access to the laser beam shall be controlled by key entry. Human access to all laser

radiation and collateral radiation in excess of the Class 1 AEL shall be prevented when the terminals of the connector produce an open circuit.

10.5.7 Unintentional Output. No single operator error or equipment failure shall cause unintentional laser output that exceeds the ANSI Z136.1 Class 1 AEL. At least two operator actions shall be required to cause the laser to function. One of these shall serve as a laser arming control. Laser emission shall not be possible when this control is in the safe position.

The laser system shall be designed to preclude unintentional self-oscillation, mode locking, double pulsing, or unwanted modes, when practical. Beams with an external focus should not be generated unless operationally necessary. Lasers and associated optics shall be designed without extraneous, external, secondary beams. Hot spots and collateral radiation should be minimized. Masking can be used to block extraneous beams.

10.5.8 Frequency Shifted and Multiple Wavelength Lasers. Laser systems that employ frequency shifting or harmonic generators to alter the fundamental output wavelength and laser systems that produce multiple wavelengths of radiation shall reduce emission of the unused wavelengths to below the applicable Class 1 AEL.

10.5.9 Airborne Lasers. Laser systems installed on aircraft that produce an external open beam shall be designed to prevent laser output while the aircraft is not airborne. However, a defeating switch, protected from inadvertent activation, may be provided to override the ground interlock and allow for ground operation, maintenance, or service. If such an override is available, it shall provide an indication that the control measure has been defeated.

10.5.10 Beam Pointing. Laser product design shall ensure that boresight retention is designed consistently with system mission requirements and shall include software systems safety. For systems with automatic target tracking capability, an automatic disable capacity shall be incorporated. This disable capacity shall inhibit laser firing if target tracking outside the system specifications occurs, or when the laser sight line reaches the gimbals limits or the system mask limit. At least two independent systems shall be capable of disabling the laser if hardware stops are not installed. A provision to override these automatic features is permitted for military combat lasers during combat.

10.5.11 Training Mode. When a training mode for the laser is required, provisions shall be made to reduce the hazardous emissions to the lowest level consistent with training requirements. This provision may be accomplished by a beam attenuator, beam expander, or diffuser on the laser. Alternately, separate systems such as a less hazardous laser, TV cameras, etc. may be used to meet this requirement. When the laser can be used in both a mission and training mode, a visual indication shall be provided to inform the operator that the laser is positively in the training mode.

10.5.12 Exit Port Cover. A cover for the exit port of the laser may be considered. If such a cover is used as a safety control measure, it shall be designed to withstand repeated laser firings, clearly indicate when it is in the safe position, and be permanently attached to the laser.

10.5.13 Interlocks. Housings confining high-voltage electrical access points or hazardous laser or collateral radiation shall be interlocked to protect personnel. Visual or aural indication of interlock defeat shall be required. Interlocks shall return to their normal operation when access cover or door is returned.

10.5.14 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.

10.5.15 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. Control measures based on the most hazardous exposure condition shall be used.

10.5.16 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 should be used to indicate changes in performance that

increases the NOHD or optical radiation hazards, of an existing system.

11. Related Standards

This document serves as a companion to the SAE Aerospace Standard AS4970, 21CFR1040, FAA 7400.2 and related FAA documents, Military Standard 1425, and Military Handbook 828, for determining the hazards from outdoor laser operations.

11.1 ANSI Standards.

When any of the following American National Standards referred to in this document is superseded by a revision approved by the American National Standards Institute, Inc, the revision shall apply:

American National Standard for Safe Use of Lasers Z136.1-2000

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

American National Standard Recommended Practice for Laser Safety Measurements for Hazard Evaluation, Z136.4-2005

American National Standard Compressed Gas Cylinder Valve Outlet and Inlet Connections, ANSI/CGA V-1-1977

American National Standard National Electrical Code, ANSI/NFPA 70-1984

American National Standard Safety Standard for Radio Receivers, Audio Systems, and Accessories, ANSI/UL 1270-1978

American National Standard General Safety Standard for Installations Using Non-Medical X-Ray and Sealed Gamma-Ray Sources, Energies up to 10 MeV, ANSI/N543-1974 (reaffirmed in 1989)

American National Standard Specifications for Accident Prevention Signs, ANSI Z535.1-1998

American National Standard Product Safety Signs and Labels, ANSI Z535.4-2002

American National Standard Method of Marking Portable Compressed Gas Containers to Identify the Material Contained, ANSI/CGA C-4-1978

American National Standard Practice for Occupational and Educational Eye and Face Protection, ANSI Z87.1-1989

American National Standard for Industrial Robots and Robot Systems-Safety Requirements, ANSI/RIA R15.06-1986

American National Standard Fundamentals Governing the Design and Operation of Local Exhaust Systems, ANSI Z9.2-1979

American National Standards Institute/ American Society of Safety Engineers, Control of Hazardous Energy – Lockout/ Tagout and Alternative Methods, ANSI/ ASSE Z244.1-2003

11.2 Other Standards and Codes.

ACGIH: Industrial Ventilation: A Manual of Recommended Practice (latest revision)

ACGIH: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices (latest revision)

FDA/CDRH Federal Laser Product Performance Standard (FLPPS), 21 CFR Part 1040

IEC 60825-1, Safety of Laser Products – Part 1: Equipment classification, requirements and user's guide, edition 1, 1993, with amendment 1: 1997, and amendment 2: 2001. (issued as a consolidated document as IEC60825-1, edition 1.2: 2001-08 in 2001)

IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz, IEEE C95.1-1991, (1999 ed)

IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0 to 3 kHz, IEEE C95.6-2002

National Electrical Code, Section 110-16, Work Space About Electric Equipment (600 Volts Nominal or Less)

National Fire Protection Association NFPA 30, Flammable and Combustible Liquids; NFPA 115, Laser Fire Protection, 2003

OSHA: Occupational Safety and Health Standards for General Industry, 29 CFR1910:

1910.95 - Occupational Noise Exposure

1910.134 - Respiratory Protection

1910.147 - The Control of Hazardous Energy (lockout/tagout)

1910.309-330 - Electrical Safety Related Work Practices

1910, Subpart Z - Toxic and Hazardous Substances

OSHA Directive, Pub 8-1.3 Guidelines for Robotics Safety, 1987

OSHA Technical Manual TED 1-0.15A, Section III, Chapter 6, Laser Hazards

SAE International, The Engineering Society for Advancing Mobility Land Sea Air and Space, Aerospace Standard, AS4970, Human Factors Considerations for Outdoor Laser Operations in the Navigable Airspace, 1999-1

SAE International, ARP5535, "Observers for Laser Safety in the Navigable Airspace", 2003-07

SAE International, ARP5572, "Control Measures for Laser Safety in the Navigable Airspace", 2004

FAA, AC No. 70-1, "Advisory Circular: Outdoor Laser Operations", 2004

FAA, AC No. 70-2, "Advisory Circular: "Reporting of Laser Illumination of Aircraft", 2005

International Civil Aviation Organization (ICAO), "Manual on Laser Emitters and Flight Safety," Doc 9815, AN/447, First Edition—2003

Table 1. Photopic Luminous Efficiency Function $V(\lambda)$. Effective irradiance is obtained by multiplying the actual irradiance by $V(\lambda)$.*

Laser Wavelength (μm)	$V(\lambda)$	Laser Wavelength (μm)	$V(\lambda)$
0.380	0.00004	0.585	0.8100
0.385	0.00007	0.590	0.7580
0.390	0.00012	0.595	0.7100
0.395	0.00018	0.600	0.6330
0.400	0.00040	0.605	0.5800
0.405	0.00058	0.610	0.5030
0.410	0.0012	0.615	0.4500
0.415	0.0020	0.620	0.38200
0.420	0.0040	0.625	0.32500
0.425	0.0065	0.630	0.26500
0.430	0.0116	0.635	0.21500
0.435	0.0170	0.640	0.17500
0.440	0.0230	0.645	0.13200
0.445	0.0300	0.650	0.10700
0.450	0.0380	0.655	0.07500
0.455	0.0500	0.660	0.06100
0.460	0.0600	0.665	0.04350
0.465	0.0720	0.670	0.03210
0.470	0.0910	0.675	0.02250
0.475	0.1050	0.680	0.01700
0.480	0.1390	0.685	0.01060
0.485	0.1620	0.690	0.00820
0.490	0.2080	0.695	0.00590
0.495	0.2500	0.700	0.00410
0.500	0.3230	0.705	0.00300
0.505	0.4000	0.710	0.00210
0.510	0.5030	0.715	0.00140
0.515	0.6200	0.720	0.00100
0.520	0.7090	0.725	0.00077
0.525	0.8000	0.730	0.00052
0.530	0.8620	0.735	0.00035
0.535	0.9250	0.740	0.00025
0.540	0.9540	0.745	0.00018
0.545	0.9800	0.750	0.00012
0.550	0.9900	0.755	0.000085
0.555	1.0000	0.760	0.000060
0.560	0.9900	0.765	0.000042
0.565	0.9700	0.770	0.000030
0.570	0.9520	0.775	0.000020
0.575	0.9100	0.780	0.000015
0.580	0.8700		

*The listed CIE normalized photopic luminous efficiency function $V(\lambda)$ is photopic for a standard observer. The illuminance (lm cm^{-2}) is the measured irradiance multiplied by $V(\lambda)$ and 683 lumen/watt. The effective irradiance (W cm^{-2}) is the actual (measured) irradiance multiplied by $V(\lambda)$.

Table 2. Selected MPEs. Values are for selected wavelengths for exposure durations usually less than 10 seconds.

Wavelength (μm)	Exposure Duration (s)	MPE	
		Pulsed ($\text{J}\cdot\text{cm}^{-2}$)	CW ($\text{W}\cdot\text{cm}^{-2}$)
0.180 to 0.302*	10^{-9} to 3×10^4	3×10^{-3}	$3\times 10^{-3}\times T_{\text{max}}^{-1}$
0.302 to 0.315*†	10^{-9} to 3×10^4	$10^{200(\lambda-0.295)}\times 10^{-4}$	$10^{200(\lambda-0.295)}\times 10^{-4}\times T_{\text{max}}^{-1}$
0.315 to 0.400	10^{-9} to 10	$0.56\times t^{0.25}$	$0.56\times T_{\text{max}}^{-0.75}$
0.400 to 1.050	10^{-13} to 10^{-11} 10^{-11} to 10^{-9} 10^{-9} to 18×10^{-6} 18×10^{-6} to 10 0.25 10	$1.5\times C_A\times 10^{-8}$ $2.7\times C_A\times t^{0.75}$ $0.5\times C_A\times 10^{-6}$ $1.8\times C_A\times t^{0.75}\times 10^{-3}$ $0.64\times C_A\times 10^{-3}$ $10\times C_A\times 10^{-3}$	$1.8\times C_A\times T_{\text{max}}^{-0.25}\times 10^{-3}$ $2.6\times C_A\times 10^{-3}$ $1.0\times C_A\times 10^{-3}$
1.050 to 1.400	10^{-13} to 10^{-11} 10^{-11} to 10^{-9} 10^{-9} to 50×10^{-6} 50×10^{-6} to 10 10	$1.5\times C_C\times 10^{-7}$ $27\times C_C\times t^{0.75}$ $5.0\times C_C\times 10^{-6}$ $9\times C_C\times t^{0.75}\times 10^{-3}$ $50\times C_C\times 10^{-3}$	$9\times C_C\times T_{\text{max}}^{-0.25}\times 10^{-3}$ $5\times C_C\times 10^{-3}$
1.400 to 1.500	10^{-9} to 10^{-3} 10^{-3} to 10 10	0.1 $0.56\times t^{0.25}$ 1	$1/(10\times T_{\text{max}})$ $0.56\times T_{\text{max}}^{-0.75}$ 0.1
1.500 to 1.800	10^{-9} to 10 10	1 1	$1/T_{\text{max}}$ 0.1
1.800 to 2.600	10^{-9} to 10^{-3} 10^{-3} to 10 10	0.1 $0.56\times t^{0.25}$ 1	$1/(10\times T_{\text{max}})$ $0.56\times T_{\text{max}}^{-0.75}$ 0.1
2.600 to 10^3	10^{-9} to 10^{-7} 10^{-7} to 10 10	10×10^{-3} $0.56\times t^{0.25}$ 1	$0.56\times T_{\text{max}}^{-0.75}$ 0.1

*For the wavelength band of 0.180 to 0.314 μm , the exposure is considered photochemical and additive over a full day of exposure. In addition, the MPE has a thermal limit of $0.56\times t^{0.25}$ J cm^{-2} , which could result in a lower MPE for pulsed lasers. The pulse correction factor, C_P is applied to the thermal limit, but not to the photochemical limit.

†For the wavelength band of 0.303 to 0.314 μm , the computed values given by the equation are only approximate. See ANSI Z136.1 for exact values.

$C_A = 1.0$ for $\lambda = 0.4$ to 0.7 μm

$C_A = 10^{2(\lambda-0.7)}$ for $\lambda = 0.7$ to 1.05 μm

$C_A = 5.0$ for $\lambda = 1.05$ to 1.4 μm

$C_C = 1.0$ for $\lambda = 1.05$ to 1.15 μm

$C_C = 10^{18(\lambda-1.15)}$ for $\lambda = 1.15$ to 1.2 μm

$C_C = 8.0$ for $\lambda = 1.2$ to 1.4 μm

C_E shall be applied to both the pulsed and CW thermal MPE for the retinal hazard region.

The photochemical MPE, for extended source lasers with wavelengths between 0.400 μm and 0.600 μm for exposure durations longer than 0.7 s, may be lower than the thermal MPE, and would therefore apply. Refer to ANSI Z136.1 for MPEs for these types of lasers. The three rules from section 8.2.1 shall be applied to the MPE for repetitive pulse lasers.

Table 3. Limiting and Measurement Apertures.

Wavelength (μm)	T_{max} or t (s)	D_f^* Unaided (mm)	$D_c^\dagger$ Aided (mm)	Transmission of optics ‡ (%)	D_c & D_f Skin (mm)
0.180 – 0.302	10^{-9} - 0.3	1.0	N/A	< 2	3.5
	0.3 - 10	$1.5 t^{0.375}$	N/A	< 2	3.5
	10 - 30k	3.5	N/A	< 2	3.5
0.302 – 0.400	10^{-9} - 0.3	1.0	7.0	< 70	3.5
	0.3 - 10	$1.5 t^{0.375}$	$11 t^{0.375}$	< 70	3.5
	10 - 30k	3.5	25.0	< 70	3.5
0.400 – 0.700	10^{-13} - 30k	7.0	50.0	< 90	3.5
0.700 – 1.400	10^{-13} - 30k	7.0	50.0	< 70	3.5
1.400 – 4.000	10^{-9} - 0.3	1.0	7.0	< 70	3.5
	0.3 - 10	$1.5 t^{0.375}$	$11.0 t^{0.375}$	< 70	3.5
	10 - 30k	3.5	25.0	< 70	3.5
$4.000 - 10^3$	10^{-9} - 0.3	1.0	N/A	< 2	3.5
	0.3 - 10	$1.5 t^{0.375}$	N/A	< 2	3.5
$10^3 - 10^5$	10 - 30k	3.5	N/A	< 2	3.5
	10^{-9} - 30k	11.0	N/A	< 2	11.0

*The limiting aperture is the smallest aperture for which irradiance and radiant exposure should be averaged over, when compared to MPE values. For unaided viewing, these apertures are applied directly to measured or calculated values.

† For optically aided viewing, a 7 power optical system is usually assumed for a hazard evaluation. An ideal pair of 7 $\times$ 50 binoculars would have a 50 mm entrance aperture and a 7 mm exit aperture, which results in about 7.14 magnifying power. Therefore, the measurement apertures listed in this column are 7 times those of the previous column for those wavelengths expected to transmit laser energy.

‡ When measurement apertures are larger than the limiting aperture due to the possibility of magnifying optics being used, the measured or calculated irradiance or radiant exposure is multiplied by a reasonable transmission value such as that listed in this column.

Table 4. Correction Factor, C(Q), for Pulsed Lasers.*

Pulse Repetition Frequency (kHz)	MPE _{pulsed} /MPE _{cw} Wavelengths 0.4 –1.05 μm C(Q)	Pulse Repetition Frequency† (kHz)	MPE _{pulsed} /MPE _{cw} Wavelengths 0.4 –1.05 μm C(Q)	MPE _{pulsed} /MPE _{cw} Wavelengths 1.05-1.4 μm C(Q)
55	1.00	24	0.54	1.00
54	0.98	23	0.52	1.00
53	0.97	22	0.50	1.00
52	0.96	21	0.48	0.97
51	0.94	20	0.47	0.93
50	0.93	19	0.45	0.90
49	0.91	18	0.43	0.86
48	0.90	17	0.41	0.83
47	0.89	16	0.40	0.79
46	0.87	15	0.38	0.75
45	0.86	14	0.36	0.72
44	0.84	13	0.34	0.68
43	0.83	12	0.32	0.64
42	0.81	11	0.30	0.60
41	0.80	10	0.28	0.56
40	0.79	9	0.26	0.51
39	0.77	8	0.23	0.47
38	0.76	7	0.21	0.43
37	0.74	6	0.19	0.38
36	0.73	5	0.17	0.33
35	0.71	4	0.14	0.28
34	0.70	3	0.11	0.23
33	0.68	2	0.08	0.17
32	0.66	1	0.05	0.10
31	0.65			
30	0.63			
29	0.62			
28	0.60			
27	0.59			
26	0.57			
25	0.55			

*The MPE for repetitive pulse, Q-switched lasers is the average power MPE multiplied by C(Q) (for visible and near infrared lasers for short exposures of 0.25 s or 10 s). Listed values provide a minimum value for other pulsed lasers. The MPE for lasers that operate at a PRF greater than the critical PRF is the same as for CW lasers. Correction factors are 1.0 and are therefore not listed for PRFs greater than 24 kHz for wavelengths greater than 1.05 μm since the critical PRF is 22 kHz for these wavelengths.

†The MPEs in terms of irradiance for PRFs less than 1 kHz are not provided in this table. These MPEs may be calculated by multiplying the PRF by the computed MPE/pulse in terms of radiant exposure (see 8.2.1).

Table 5. Visual Interference Levels.*

Flight Zone or Region of Visual Interference‡	Visual Interference Levels		
	Effective Radiant Exposure (J·cm ⁻²)† $T_{\max} \leq 0.25$ s	Effective Irradiance (W·cm ⁻²)† $T_{\max} > 0.25$ s	Illuminance (lm·cm ⁻²)†† $T_{\max} > 0.25$ s
Sensitive	25×10^{-6}	100×10^{-6}	6.8×10^{-2}
Critical	1.25×10^{-6}	5.0×10^{-6}	3.4×10^{-3}
Laser-Free	12.5×10^{-9}	50×10^{-9}	3.4×10^{-5}

*Levels are listed from visible lasers used at dusk or night.

†Measured (or calculated) irradiance levels are multiplied by the photopic luminance efficiency coefficient obtained from Table 1 in order to correct for visual sensitivity of the human eye. The irradiance levels for the normal region are not corrected for visual effect using $V(\lambda)$ since these levels correspond to the MPE. The formula provides MPE values for exposure durations from 18 μ s to 0.25 s. Whenever the irradiance exceeds the MPE, the MPE takes precedence even if the visual interference level is higher.

‡The normal region is limited by the MPE, which is not wavelength dependent in the visible spectrum. The MPE expressed as actual irradiance or radiant exposure is applicable for this region.

††The listed value for illuminance is only for a laser with a wavelength of 0.55 μ m. The visual interference level for other wavelengths may be calculated by multiplying the provided value by $V(\lambda)$ from Table 1.

Table 6. Skin MPEs.*

Wavelength (μ m)	Exposure Duration (s)	MPE	
		Pulsed (J·cm ⁻²)	CW (W·cm ⁻²)
0.180 to 0.314	10^{-9} to 3×10^4	Same as Table 2	Same as Table 2
0.315 to 0.400	10^{-9} to 10	$0.56 \times t^{0.25}$	$0.56 \times T_{\max}^{-0.75}$
0.400 to 1.400	10^{-9} to 10^{-7}	$0.2 \times C_A \times 10^{-3}$	$1.1 \times C_A \times T_{\max}^{-0.75}$
	10^{-7} to 10	$1.1 \times C_A \times t^{0.25}$	$0.2 \times C_A$
1.400 to 1.0×10^3	10	$2.0 \times C_A$	See Table 2
	10^{-9} to 10	See Table 2	

* Values are for selected wavelengths for exposure durations less than 10 s (except for UV).

Table 7. Diffuse Reflection Hazards from Visible CW Laser Beams.*

Beam Diameter (mm)	Viewing Distance								
	20 cm	30 cm	40 cm	50 cm	60 cm	70 cm	80 cm	90 cm	1 m
	Beam Power (W)								
0.3	3	7	13	20	29	39	51	65	80
0.4	4	7	13	20	29	39	51	65	80
0.5	5	8	13	20	29	39	51	65	80
0.6	6	10	13	20	29	39	51	65	80
0.7	7	11	15	20	29	39	51	65	80
0.8	9	13	17	21	29	39	51	65	80
0.9	10	14	19	24	29	39	51	65	80
1.0	11	16	21	27	32	39	51	65	80
1.1	12	18	23	29	35	41	51	65	80
1.2	13	19	26	32	38	45	51	65	80
1.3	14	21	28	35	42	49	55	65	80
1.4	15	22	30	37	45	52	60	67	80
1.5	16	24	32	40	48	56	64	72	80
1.6	17	26	34	43	51	60	68	77	85
1.7	18	27	36	45	54	63	72	82	91
1.8	19	29	38	48	58	67	77	86	96
1.9	20	30	40	51	61	71	81	91	100
2.0	21	32	43	53	64	75	85	96	110
3.0	32	48	64	80	96	110	130	140	
4.0	43	64	85	110	130	150			
5.0	53	80	110	130					
6.0	64	96	130						
7.0	75	110							
8.0	85	130							
9.0	96								

*Power values listed in the table in W are those that will barely produce a momentary (0.25 s) diffuse reflection hazard from a CW visible laser. The value is provided at various viewing distances, and various beam diameters at the point of impact on a white matte target (wavelengths from 0.4 μm to 0.7 μm). For 10 s viewing, the listed values should be reduced by a factor of 2.5.

Table 8. Diffuse Reflection Hazard from Pulsed Lasers in Retinal Hazard Region.*

Beam Diameter (mm)	Viewing Distance								
	20 cm	30 cm	40 cm	50 cm	60 cm	70 cm	80 cm	90 cm	1 m
	Beam Energy (mJ)								
1	2	3	4	5	6	8	10	13	16
2	4	6	8	11	13	15	17	19	21
3	6	10	13	16	19	22	25	28	31
4	9	13	17	21	25	29	34	38	42
5	11	16	21	26	32	37	42	47	53
6	13	19	25	32	38	44	51	57	63
7	15	22	30	37	44	52	59	66	74
8	17	26	34	43	51	59	68	76	84
9	20	29	39	48	57	67	76	86	95
10	22	32	43	53	64	74	85	95	106
20	46	67	88	109	130	151	172	193	214
30	109	104	135	167	198	229	261	292	323
40	203	191	185	226	268	310	352	394	436
50	331	307	295	288	341	393	445	498	550
60	498	456	435	423	415	478	541	604	666
70	708	640	607	587	574	565	639	712	785
80	965	860	811	781	762	749	739	822	906
90	1272	1121	1049	1007	980	960	946	935	1029
100	1635	1425	1325	1266	1228	1202	1182	1166	1154

*Energy values listed in the table in mJ are those that will barely produce a diffuse hazard for Q-switched lasers at various viewing distances. Values listed are based on various beam diameters, at the point of impact on a white matte target, for wavelengths in retinal hazard region.

Notes:

1. For wavelengths between 0.7 μm and 1.4 μm , the above power values should be multiplied by factors of C_A and C_C as appropriate.
2. For wavelengths between 1.05 μm and 1.4 μm , the above values are multiplied by an additional factor of 2.
3. For repetitive pulse lasers, the repetitive-pulse correction factor C_P should be applied.

Table 9. Magnifying Optical Sight Categories. Minimum optical density values for magnifying optical sights

Safety Category	694.3 nm	800 - 950 nm	1050 – 1065 nm
A	5.0	5.0	5.0
B	5.0	2.0	5.0
C	5.0	1.0	5.0
D	5.0	0.3	5.0
E	4.0	2.0	5.0
F	3.0	2.0	5.0
G	2.0	2.0	5.0
H	1.0	1.0	5.0
I	0.4	1.5	4.5
J	0.3	1.0	3.0
K	0.7	2.0	5.0
L	---	0.3	5.0
M	2.0	2.0	2.0
N	1.0	1.0	1.0
O	---	---	---
P	3.0	3.0	3.0

NOTE: The OD values given above are for the entire system. For example, a filter with 4.7 OD at 694.3 nm, a 5.8 OD at 1064 nm with essentially no protection in the 800 – 950 nm band would be Category D when used in conjunction with a sight with an intrinsic OD of 0.27 in the near IR, due to the intrinsic filtration of the sight.

Table 10. Non-Magnifying Optical Sight Categories. Minimum optical density values for non-magnifying optical sights

Safety Category	694.3 nm	800 - 950 nm	1050 – 1065 nm
A	3.5	3.5	3.5
B	3.5	0.5	3.5
C	3.5	---	3.5
D	3.5	---	3.5
E	2.5	0.5	3.5
F	1.5	0.5	3.5
G	0.5	0.5	3.5
H	---	---	3.5
I	---	---	3.0
J	---	---	1.5
K	---	0.5	3.5
L	---	---	3.5
M	0.5	0.5	0.5
N	---	---	---
O	---	---	---
P	1.5	1.5	1.5

NOTE: The OD values given above are for the entire system.

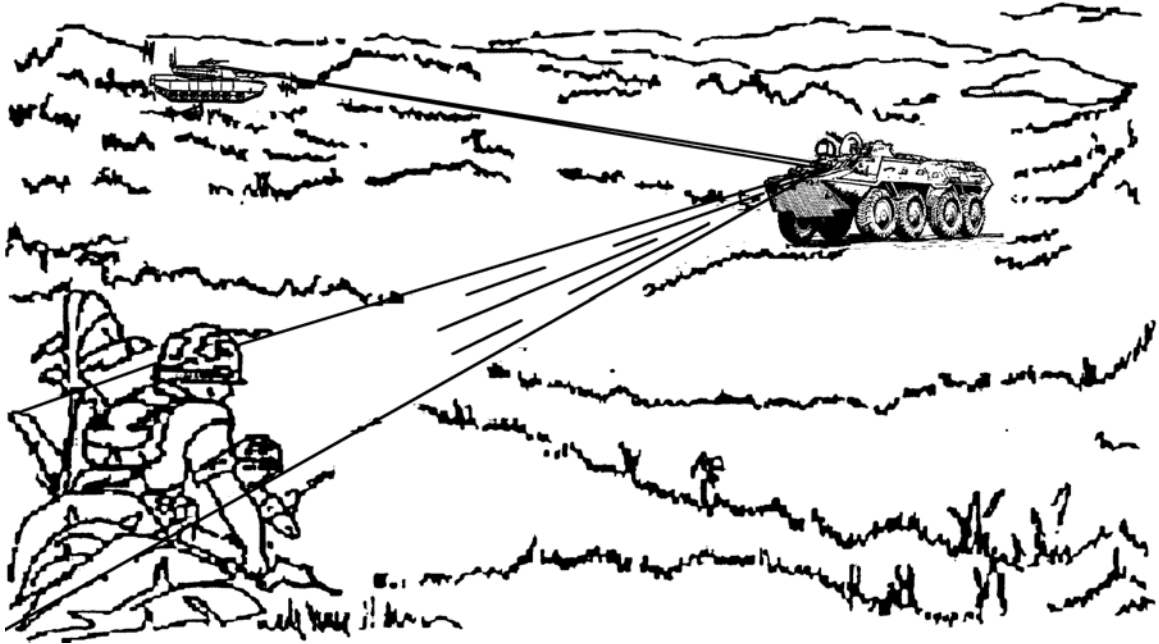


Figure 1. Specular Reflection Created from a Flat Glass Surface. Depending on the angle of the glass window on the vehicle with respect to the direction of the laser beam, personnel may be illuminated by the reflection.

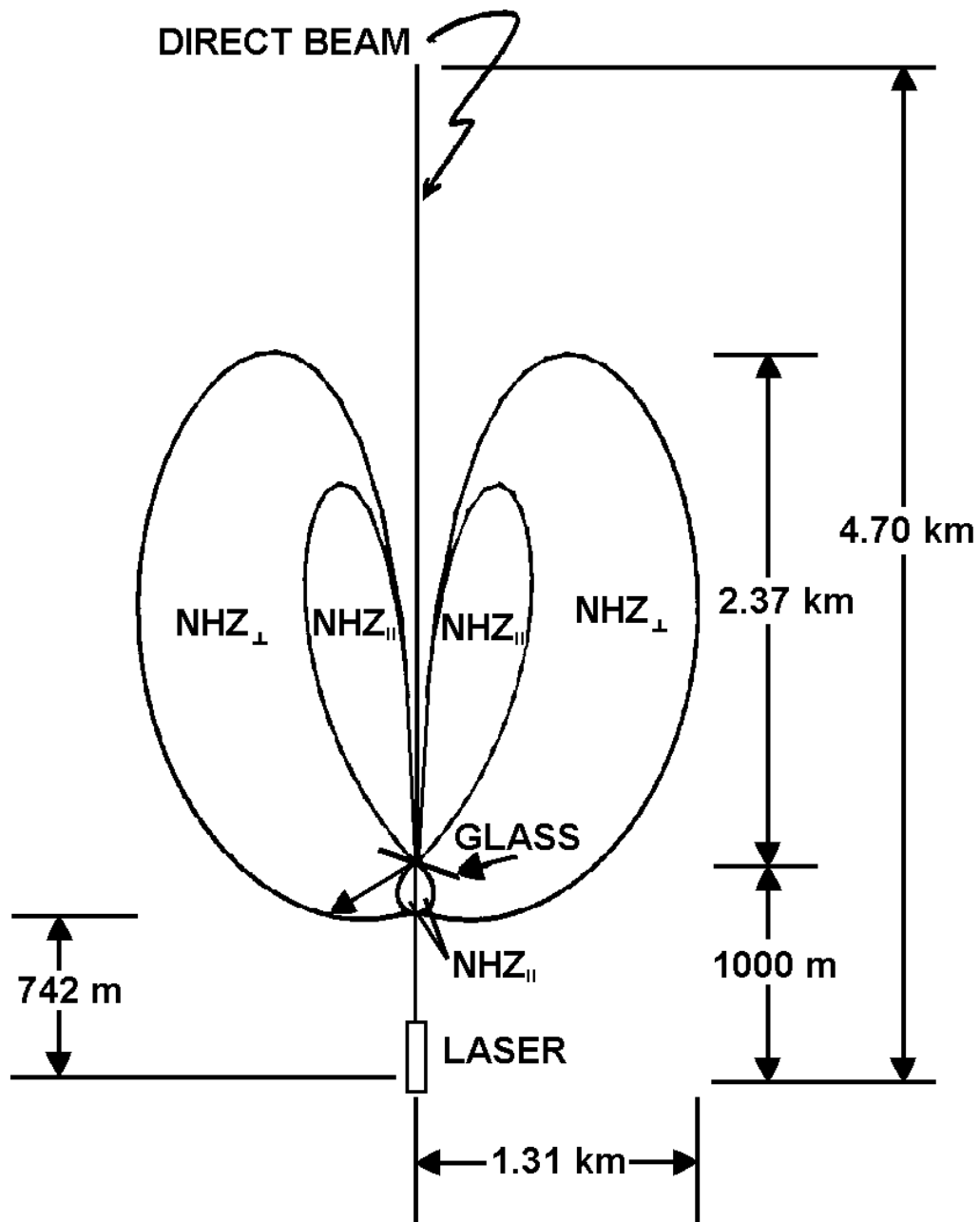


Figure 2. Specular Reflections. Nominal hazard zone created from a specular surface located near the aiming point of the laser when the orientation of the reflector is unknown. Different nominal hazard zones will be created when the polarization of the laser is either parallel or perpendicular to the reflecting surface. Distances are for an arbitrary laser system.

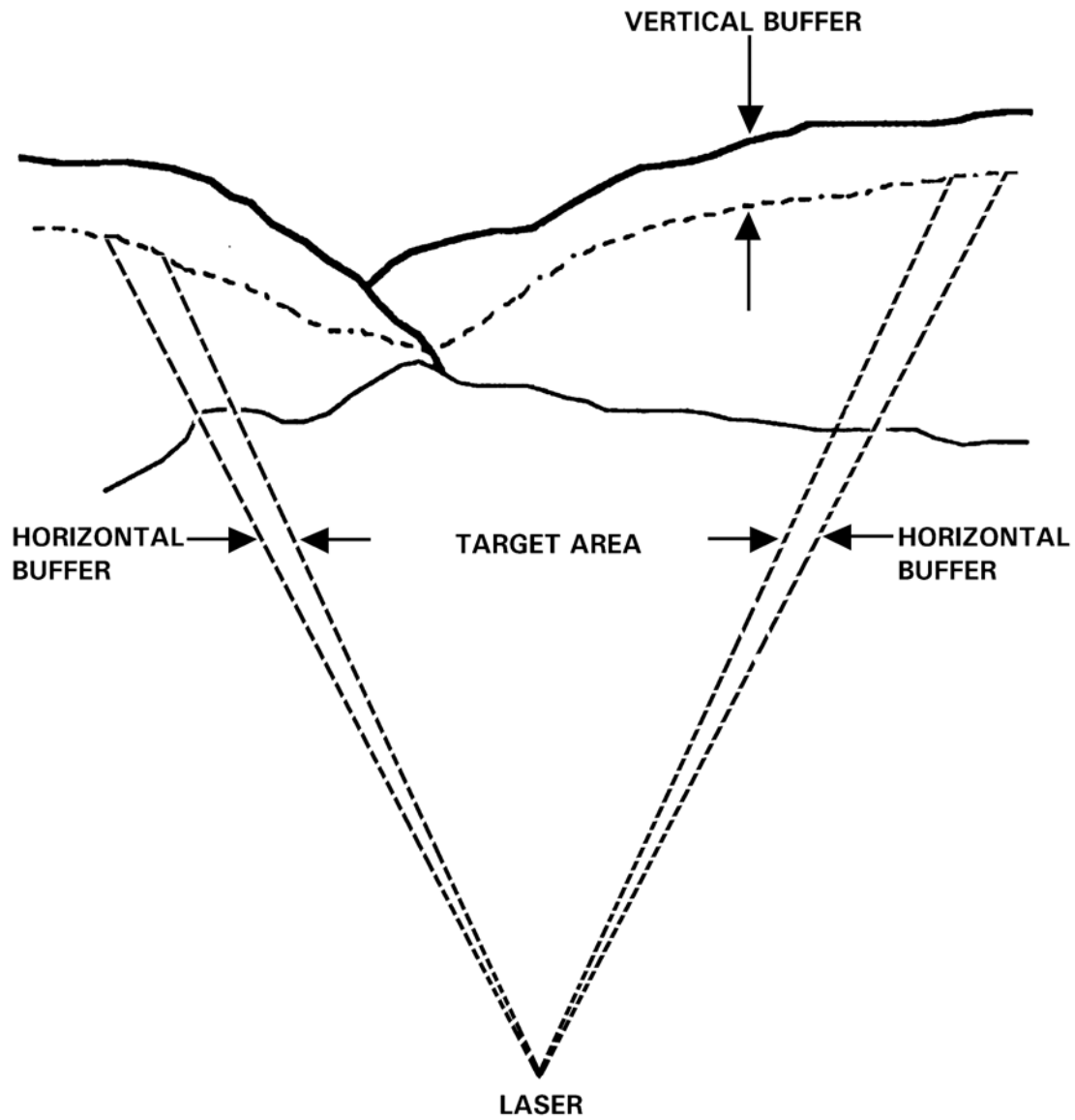


Figure 3. Laser Controlled Area on a Laser Range. Horizontal and vertical buffer areas are included. Natural terrain provides a backstop in the vertical buffer area.

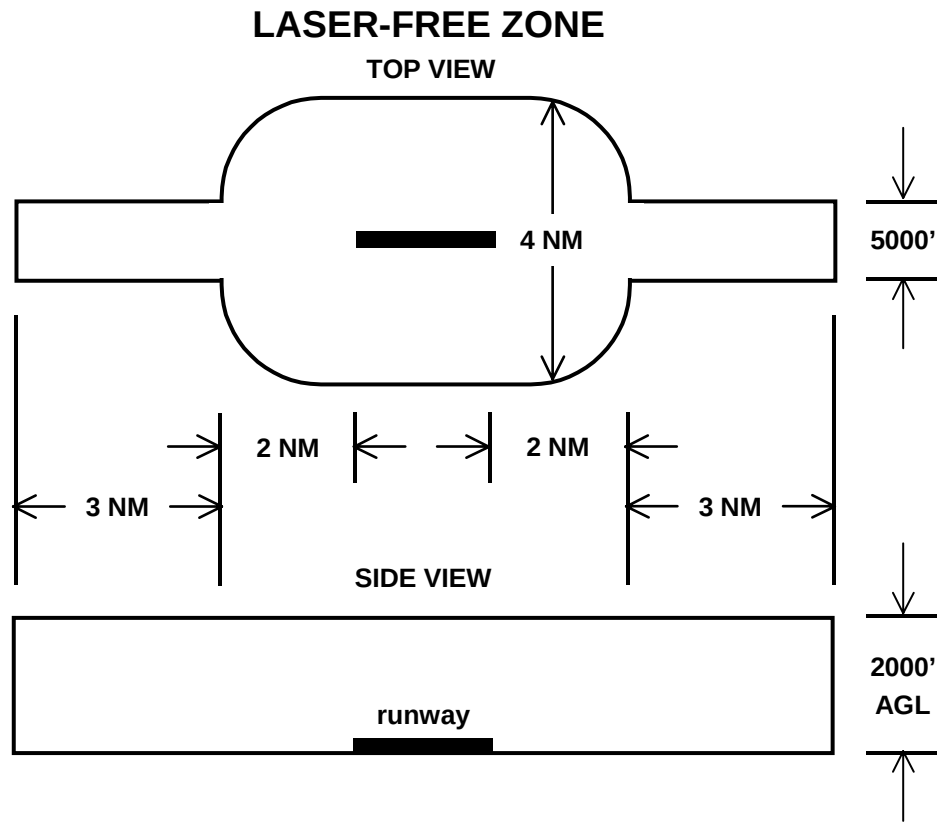


Figure 4. Laser-Free Zone next to a Single Runway. The laser-free zone includes all airspace below 2000 feet within 2 nautical miles (NM) (3.7 km) of the runway. This airspace volume is extended on each end of the runway to allow for takeoff and landing. This includes airspace 2500 feet horizontally on each side of the approach and takeoff paths for an additional 3 NM (5.5 km), for a total of 5 NM from each end of the runway.

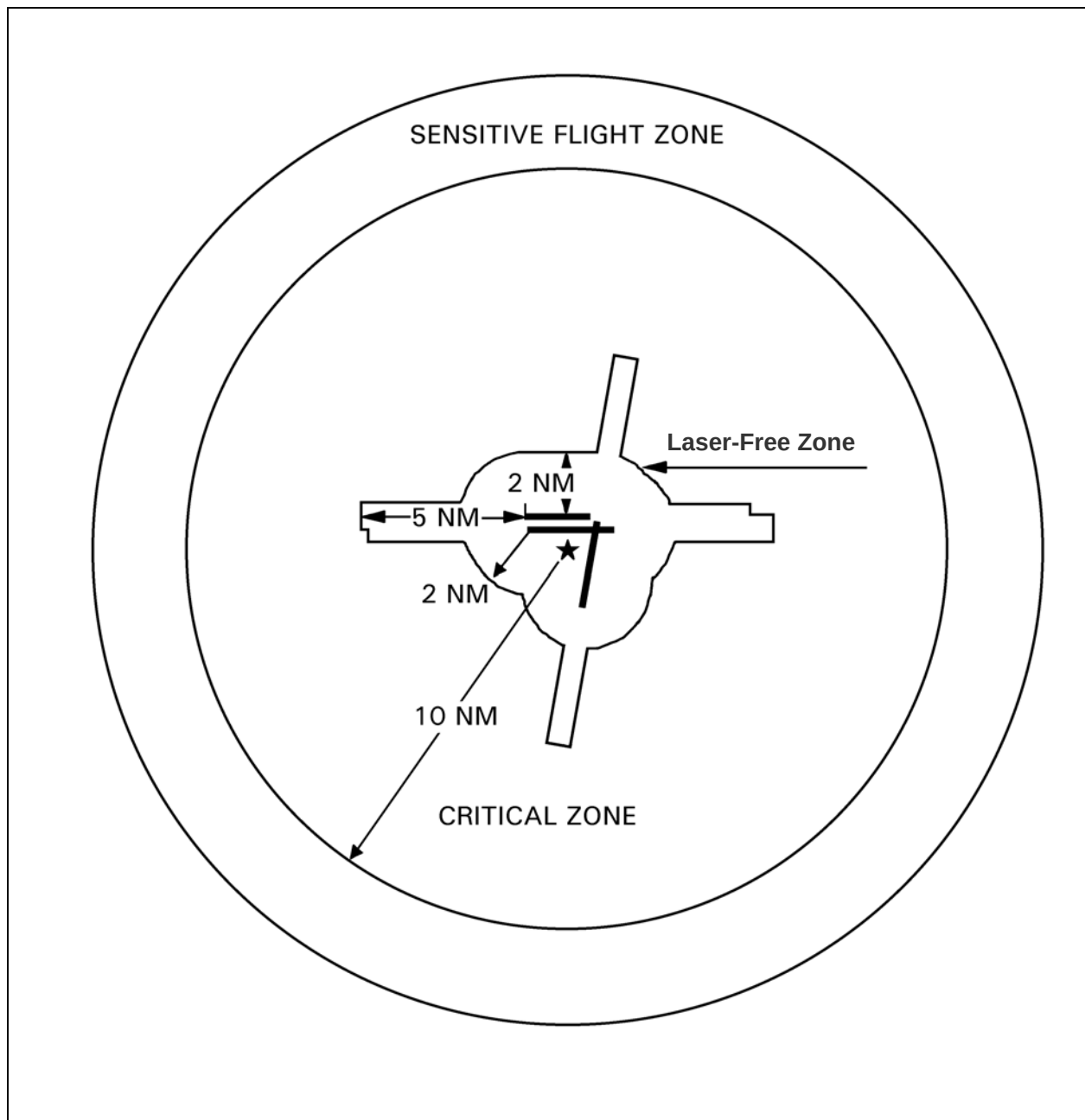


Figure 5. Interference Zones around Multiple Runways. An area within 2 NM (3.7 km) of each runway is designated as laser-free. An additional 3 NM (5.5 km) are included in the laser-free zone along the approach and takeoff paths of each runway. The critical zone extends to 10 NM from the airport reference point (marked by star), and the surrounding sensitive zone is assigned by the local FAA office (if necessary).

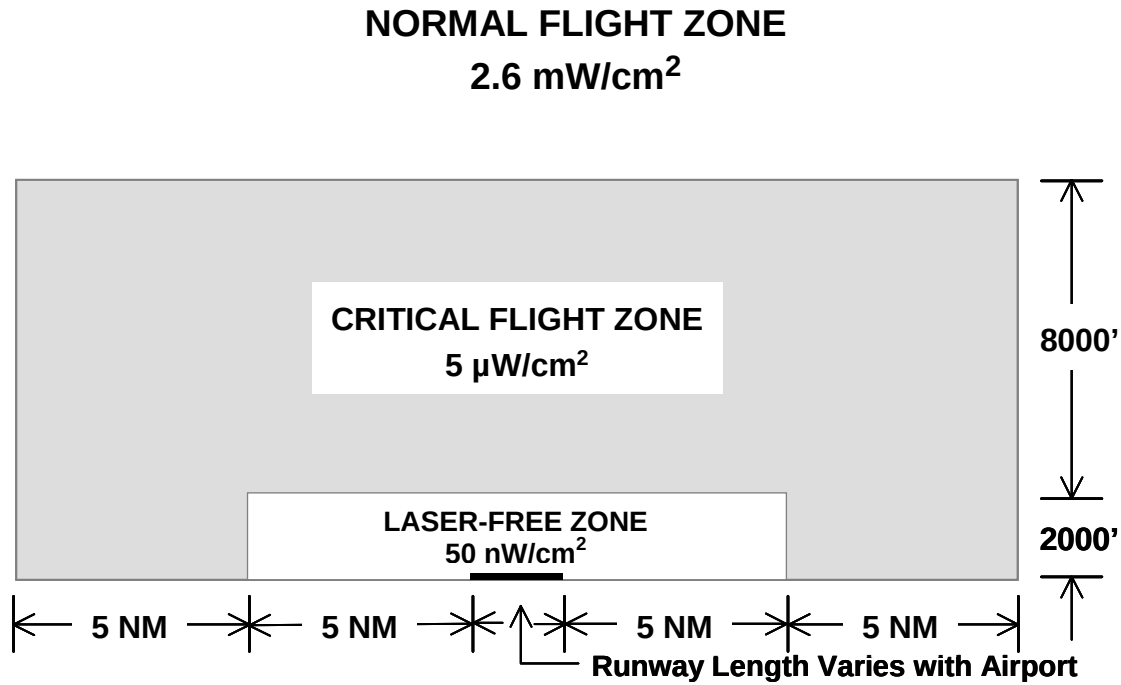


Figure 6. Profile of Flight Zones. The laser-free, critical, and normal flight zones are illustrated. The critical zone is the shaded area between the laser-free zone and the normal flight zone. A sensitive zone may be established at any location in the airport vicinity, at the discretion of the local FAA authority.

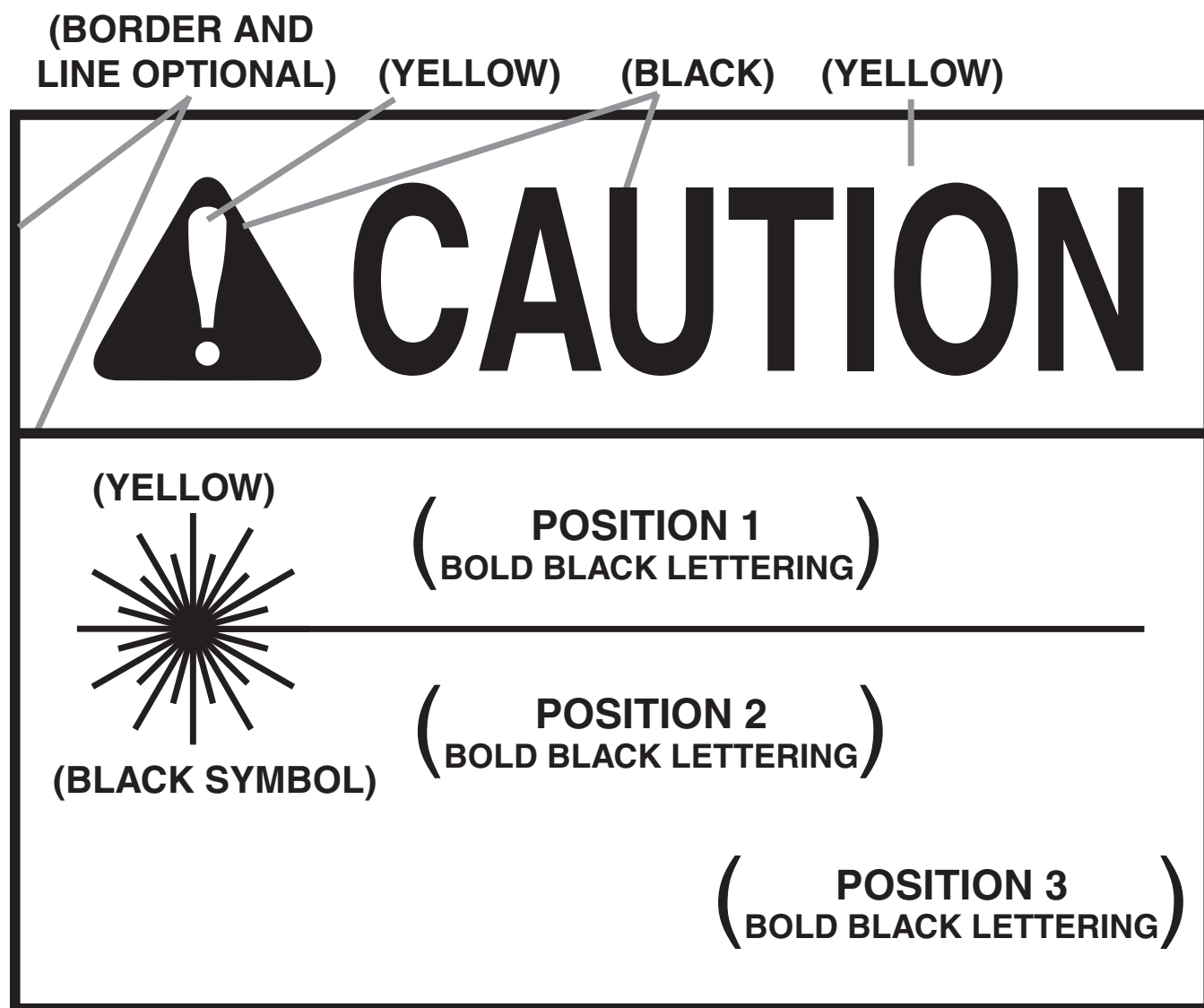


Figure 7a. Example of Caution Label. At position 1, precautionary information should be provided, such as “Do not stare into the beam” and/or “Do not view directly with optical instruments” for Class 1M or 2M products. At position 2, the type of laser should be provided, such as “Helium Neon”, and at position 3, the hazard class of the laser should be provided. Below the starburst, additional information on the characteristics of the laser should be provided such as laser wavelength and pulse characteristics.

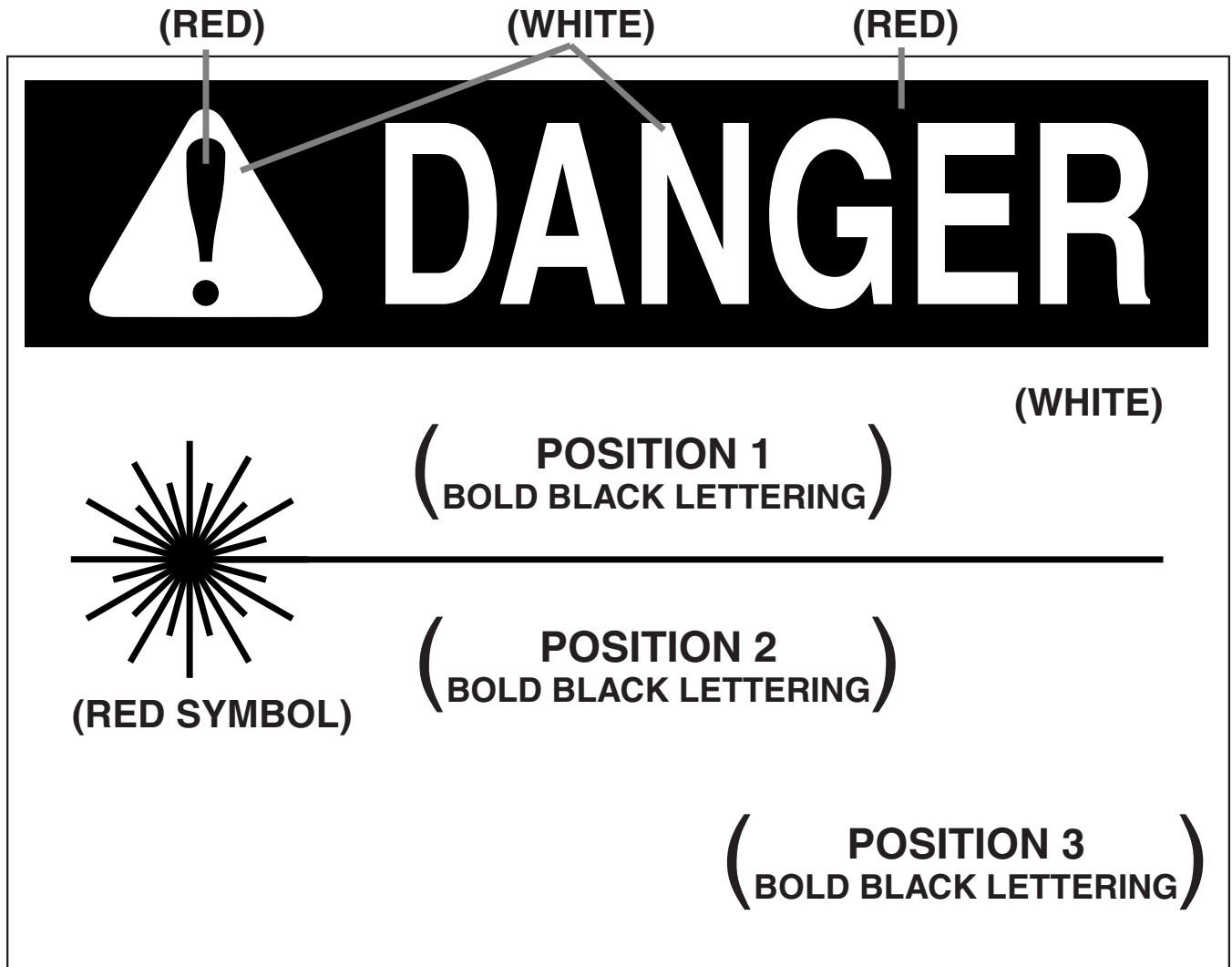


Figure 7b. Example of a Danger Label. Starburst is red; letters are black. Precautions including the NOHD would be placed above the tail of the starburst at position 1. The type of laser, including output power, pulse characteristics, and whether the output is visible or invisible, is placed below the tail of the starburst at position 2. The ANSI classification is placed in the lower right hand corner at position 3.

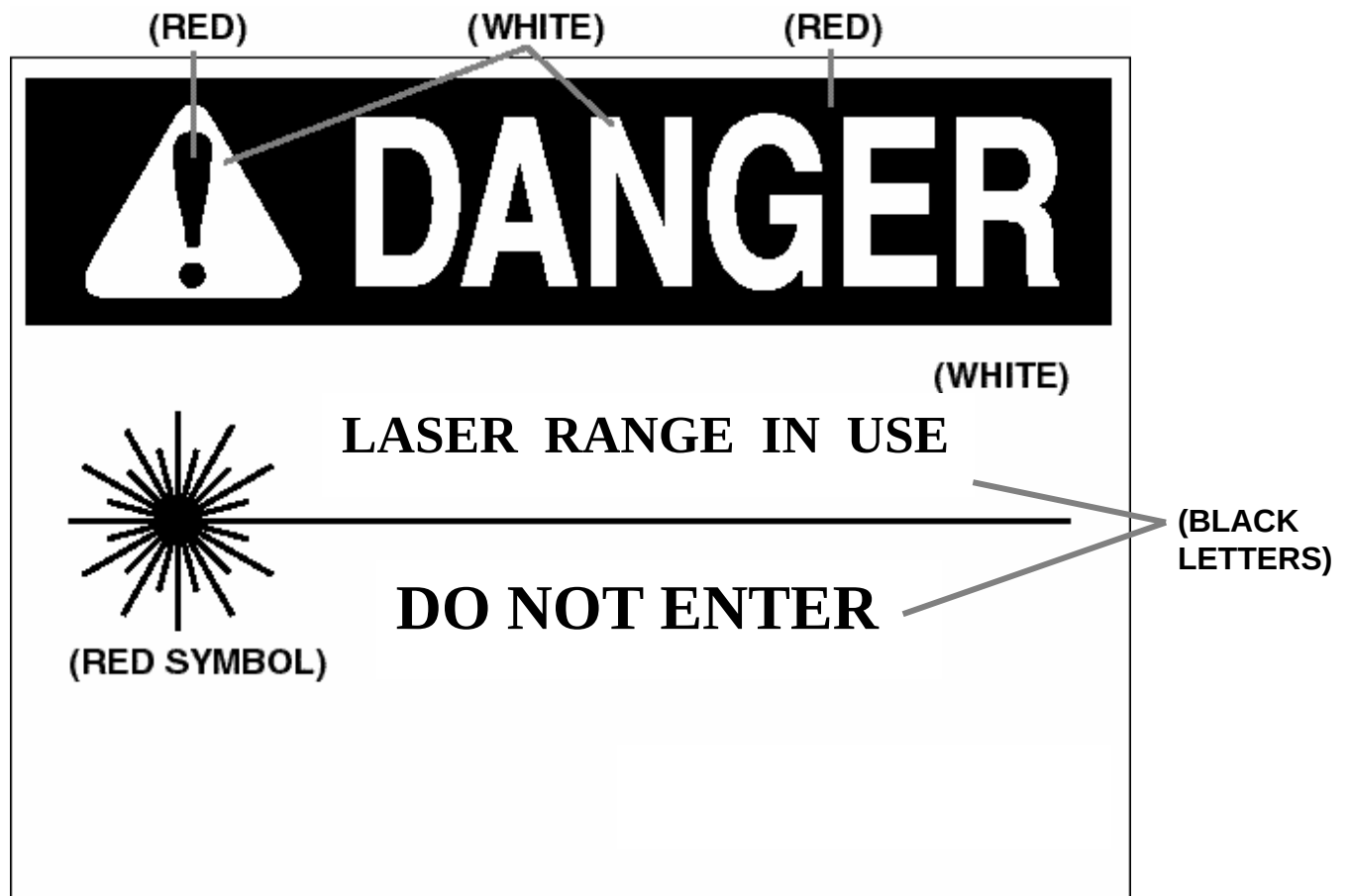


Figure 8a. Example of Temporary Laser Range Warning Sign. This sign should only be used during an actual event when the laser is operating (emitting) and should be removed when the laser is not being used.



Figure 8b. Example of Permanent Laser Range Warning Sign. This sign may remain when the laser is not being used. The temporary sign would be placed in addition to this sign during actual lasing.

Appendices

Appendix A

Administrative Requirements

A1. General.

This section contains sample letters, labels, and SOPs for operating lasers outdoors. Before operating lasers that can interfere with FAA flight operations, users should refer to FAA Order 7400.2: Part 6, Miscellaneous Procedures, Chapter 29. Before the start of operations, the user should contact the FAA Regional Office. The FAA provides forms to assist in providing the necessary information (a sample is provided in this Appendix). The FAA will then respond with a letter and let the user know if there are any objections to the use of the laser and the reasons for those objections. The user should receive a letter of non-objection from the FAA before starting operations to avoid any problems.

Labeling used for lasers intended for outdoor use may need to contain information about the operating parameters and specific instructions to avoid exposure above the MPE as shown in the sample label in Figure A1.

An SOP for safe operation is necessary for the use of all Class 3B and Class 4 lasers that have open beams. This SOP should be available for use by the operator, and others working around the laser. An example SOP is provided concerning atmospheric testing. It is convenient if it is posted near the laser for easy access. All demonstration lasers in excess of 5 mW used outdoors are required to have a variance from the FDA/CDRH.

A2. Applying for a FDA/CDRH Variance.

When the product performance requirements of 21 CFR 1040 interfere with the application of a laser device and the safe use of the device can be assured by other methods, a variance for some or all of the requirements of the Federal Laser Standard may be requested from FDA/CDRH. To request information about applying for a FDA/CDRH variance contact:

Office of Small Manufacturers Assistance
(HFZ-220)
1350 Piccard Drive
Rockville, MD 20850

The office may also be contacted by telephone (301) 443-0806. For demonstration lasers, request the regulatory information package for laser light shows. It contains, among other items, the FDA/

CDRH variance application form, and the laser light show reporting guide. These materials are used to

- (1) apply for the variance
- (2) report on operation times of the laser light show
- (3) provide details of the laser projector
- (4) explain how the show complies with the requirements of the standard
- (5) satisfy the requirements of the variance

The laser manufacturer (or organization requesting a light show variance) should submit the application form and the required reports as directed to:

Office of Compliance (HFZ-342)
Center for Devices and Radiological Health
2098 Gaither Rd.
Rockville, MD 20850

The Electronic Products Branch will then review these materials together, and if the information is complete and acceptable, a variance approval letter will be issued. If the information is incomplete or unacceptable in some way, processing of the variance will be delayed until the issues of concern are resolved in an acceptable manner.

A3. Laser Light Shows.

The Federal Laser Standard requires demonstration laser products not to exceed the accessible emission limits of Class IIIa [ANSI Class 3R (or 5 mW) for visible lasers]. Outdoor laser light shows require higher emission levels to permit them to be effective in large spaces. The laser light show provider is required to first seek and be granted a FDA/CDRH variance from the Class 3R limit before introducing shows employing laser emission levels in excess of the FDA/CDRH Class IIIa limit.

The following list of information, including the variance number and manufacturer's code are to be provided to the Federal Aviation Administration (FAA) and the Department of Defense (DoD) in notifications of outdoor laser light shows (demonstrations) that cause projections into the sky. This information is required to permit FAA and DoD jointly to do the aeronautical study necessary to

determine whether or not the proposed effects are objectionable.

A3.1 FAA Notification. Proponents of outdoor laser demonstrations are required to notify the FAA regional office and provide supporting documentation. Sample forms are included in this appendix for submitting information to the FAA, although the actual form required by the FAA may be somewhat different. The FAA notification includes the following information:

- (1) Laser group/company (point of contact)
- (2) Business addresses
- (3) Telephone number
- (4) FDA/CDRH variance number and expiration date
- (5) Date(s) and time(s) of setup and alignment
- (6) Date(s) and time(s) of shows(s)
 - (a) Show length
 - (b) Running time
- (7) Location of the show
 - (a) Show place name and address
 - (b) Latitude and longitude of the location of the show in degrees, minutes and seconds
 - (c) Maps (USGS 7.5 Quadrangle or acceptable alternate)
- (8) Class/type of laser (CW or pulsed)
- (9) Maximum emitted power (watts)/repetition frequency (kHz) at the projector as certified to FDA/CDRH
- (10) Azimuth direction of beams
- (11) Elevation of beams in degrees above the horizon
 - (a) Maximum
 - (b) Minimum
- (12) Beam divergence (milliradians)
- (13) Maximum distances from the source to where the irradiance equals 2.6 mW cm^{-2} , $100 \text{ } \mu\text{W cm}^{-2}$, and $5 \text{ } \mu\text{W cm}^{-2}$, based on maximum emitted power
- (14) Maximum altitude above the source to where the irradiance equals 2.6 mW cm^{-2} , $100 \text{ } \mu\text{W cm}^{-2}$, and $5 \text{ } \mu\text{W cm}^{-2}$, based on maximum emitted power

(15) A diagram depicting all beam arrays – terminated and unterminated

(16) Name of laser safety officer or authorized operator

(a) Local address and phone number, to include an operational telephone number at the site

(b) Additional safety procedures

i) Communications procedures during the show

ii) Visual aircraft spotters

iii) Other

(17) Quality Assurance Program, describing physical/procedural control of:

(a) Laser power

(b) Beam divergence

(c) Azimuth and elevation of beam paths

(d) Beam termination surfaces

(e) Emergency shutdown procedures

NOTE: Repetitive pulse laser data, e.g., equipment type, pulse duration, etc., is validated by the FDA/CDRH, and accompanies submission to the FAA.

(18) Supplementary information if applicable. Include the FDA/CDRH letter validating the measures that result in a smaller affected area than that shown in the Laser System Power Range Table (Table 29-2-1, FAA Order 7400.2E: Part 6. Miscellaneous Procedures; Chapter 29, Section 2, or latest revision).

A3.2 Requirements of the FDA/CDRH Variance. The FDA/CDRH variance requires that written notification is provided to the Federal Aviation Administration (FAA) and the Department of Defense (DoD) and any requirements they may specify are satisfied before conducting an outdoor laser light show. In detail, this requirement means that:

(1) All notifications are to be directed to the Air Traffic Division at the FAA regional office having jurisdiction over the area where the laser show will take place.

(2) FAA needs at least 30 days advance notice to process a request and conduct an aeronautical study. The FAA recognizes that industry conditions may not always permit the advance notice desired. While FAA endeavors to accommodate all requests, proper conduct of the aeronautical study to determine airspace effects is essential to air safety. This is

particularly true when the demonstration is in close proximity to an airport or would necessitate protection of large amounts of airspace. In these cases, it may be impossible for the FAA to respond to short notice requests.

(3) Notifications are required for all demonstrations in which laser beams may be directed or reflected into airspace (including set up, alignment, and rehearsals). Notifications should contain sufficient technical information to allow proper evaluation. The primary concern is the range and elevation from the source of the airspace that may be affected by the display.

(4) A proponent wishing to provide supplementary information about measures that will result in a smaller actual danger area than that shown in the Laser System Power Range Table in FAA Order 7400.2 should submit the data in advance to FDA/CDRH for review. The FDA/CDRH will validate the information and issue a letter to the proponent to include with their notification to the FAA.

(5) Forms and other information on certifying laser products can be found at <http://www.fda.gov/cdrh/comp/eprc.html>.

A4. Safety SOPs.

Samples of safety SOPs are provided. A safety SOP should contain the following type of information:

- (1) Name of the project or operation
- (2) Safety program overview
- (3) Laser parameters
- (4) Potential hazards
- (5) Steps for safe operation and testing
- (6) Emergency procedures for accidental exposure
- (7) Education and training requirements of staff personnel
- (8) Procedures for site evaluation and approval

A5. Laser Clearinghouse Coordination.

Some satellites have sensitive detectors that can be damaged by intense light sources originating from earth. The Air Force Space Command can determine whether a laser has the potential for interference or damage to particular satellites. Lasers with very high peak powers and very small beam divergences (sometimes as small as 10 μ rad or less) probably

have the greatest potential for producing damage to these very expensive systems.

Rather than give detailed guidance on the levels that could produce damage to satellites, criteria are provided as a starting place where coordination with space command is desirable. Lasers that can produce an instantaneous irradiance exceeding 1 mW cm⁻² at an elevation of 60,000 feet (18 km), even for 1 ns or less, should contact CMOC/J3, the Orbital Safety Officer, U.S. Space Command.

The telephone number is (719) 474-4416, or a letter may be written to:

North American Aerospace Defense Command
CMOC/J3
Attn: Orbital Safety Officer
Cheyenne Mountain AFS, CO 80914-6020

This organization has the capability to determine if the specified laser has the potential for interfering with satellites. However, if the laser is determined to have the potential for interfering with satellites, operation times and orientations of the beam can usually be assigned when the laser can be operated safely.

A6. Sample Letters and Forms.

Sample letters and forms for submission to the FAA, FDA/CDRH, and the Laser Clearinghouse are included in the following pages. Actual forms required by the FAA may differ from those included in this appendix. FAA Forms included in FAA Advisory Circulars 70-1 and 70-2 are available in the Regulatory and Guidance Library at <http://www.airweb.faa.gov>. Samples of the types of replies to be expected from these organizations are also included.

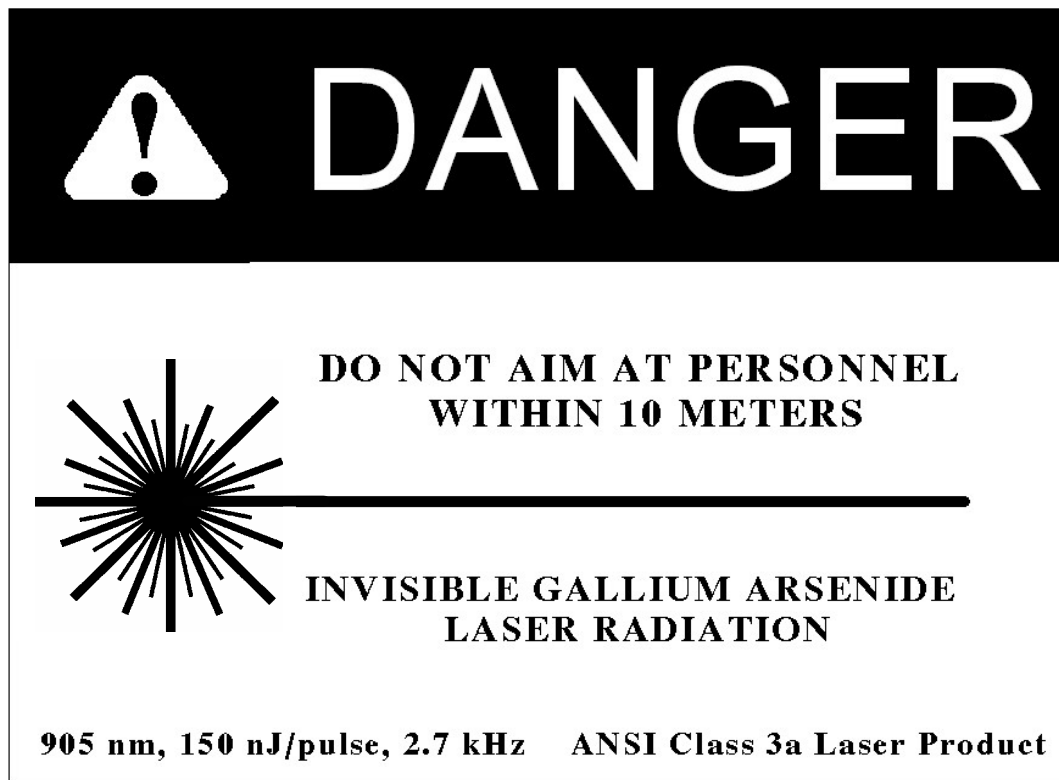


Figure A1. Example of Danger Label (for Repetitive-Pulse Gallium-Arsenide Laser).

Sample SOP

Mandatory Procedures for Laser Atmospheric Testing

(This SOP is a sample only. Actual testing may require alternate or additional controls.)

The following procedures shall be mandatory prior to, during, and immediately after any and all atmospheric testing using laser systems (Zenith mode only). Modifications to these procedures will be effective only upon receipt of a written notice. If there are any difficulties encountered with strict compliance of the following procedures, they should be brought to the immediate attention of the Radiation Safety Officer or the current chairperson of the local Nonionizing Radiation Committee (names and phone #'s).

1. Call the relevant Base of Operations and give the following information:

(a) building location.

(b) anticipated time when the atmospheric testing will commence and the duration of the test (e.g., "At approximately 0900 hours we will commence laser atmospheric testing and the tests will last for approximately 3 hours until 1200 hours.").

(c) emergency phone number and points of contact (e.g., "In the event of an emergency, you can call me at 555-1234 to notify us and we will immediately shut down the laser.").

(d) any additional information if requested by the Base of Operations personnel (e.g., type of laser, wavelength, divergence, NOHD, etc).

2. Advise the nearest Federal Aviation Administration (FAA) Approach Control a minimum of 2 hours before, and again, at 15 minutes prior to the actual operation each day and immediately upon termination of the actual operations each day.

3. As an added precaution, you are required to contact the nearest Automated Flight Service Station, and Air Traffic Control (ATC) Facility, to speak to a manager. This call is to be instigated a minimum of 6 hours before the operation, to request the issuance of a NOTAM (Notice to Airmen). The text of the NOTAM will be given to the Flight Service personnel upon initial contact. Then it should be stated that the wording of the NOTAM will remain the same for all future tests until further advised, the exception being the time of operation. A sample of the text is as follows:

"A laser operation with a light beam hazardous to direct visual observation will be conducted at (place of operations) within ½ nautical mile of: (latitude and longitude coordinates; date/time/duration). Strong caution is advised. Laser light beam may be injurious to pilots/passenger eyes within all altitudes of the beam."

4. Ensure that at least one visual observer is monitoring the airspace. This observer(s) shall be located outside and have adequate means to contact the authorized laser operator for emergency shutdown when aircraft are on course to intercept or cross the laser beam NHZ or flight hazard zone.

5. At the completion of the test, call the Base of Operations, relevant FAA, ATC, and Flight Service Station, and state that the operations have ceased (e.g., "This is (your name) of (Project Office). As of 1400 hours (time) the laser testing commenced at building (your building) has terminated."

Instructions For Completing Form**Notice Of Proposed Outdoor Laser Operation(s)****(modified from FAA Advisory Circular 70-1, Outdoor Laser Operations)**

(This form was current at the time of printing. Actual forms required by the FAA may be different.)

The information on this form will be used by the FAA Regional Office to perform an aeronautical study to evaluate the safety of a proposed laser operation. Provide all information that may be needed to perform the study. If additional details are necessary, list these in the "ATTACHMENTS" section of this form.

1. GENERAL INFORMATION – In 1.(a), enter the name, address, telephone, and fax numbers of the FAA Regional Office Air Traffic Division responsible for the area that includes the laser operation site. In 1.(b), enter the proponent's name, address, telephone, fax, and E-mail information. This is the party primarily responsible for the laser safety of this operation. When the proponent is a manufacturer or a governmental agency (e.g., NASA), and the laser is located at a different site, list the proponent here. In 1.(c), enter the event name (for temporary shows) or the facility name (for permanent installations). In 1.(d), enter the date the report is prepared or sent to FAA. It is not the date of the laser operation. - If the laser user is different than the proponent, fill in section 1.(e) Customer; if not, enter "Same as proponent." In 1.(f) enter the site address.

2. DATE(S) AND TIME(S) OF LASER OPERATION – Enter the dates and times of testing alignment procedures, and operation.

3. BRIEF DESCRIPTION OF OPERATION – The description should be a general overview of the operation. If necessary, attach additional pages.

4. ON-SITE OPERATION INFORMATION – List names and/or titles of operators. There should be at least one working, direct telephone link to the operator, or equivalent way of quickly reaching the operator (e.g., telephoning a central station that reaches operator via radio). Two telephone numbers are requested on the form; the number in 2.(c) should be used as an alternate or backup.

5. FDA/CDRH LASER LIGHT SHOW VARIANCE – List the variance number, accession number, and variance date if the operation uses or is a "demonstration laser" (generally, a laser light show) and therefore, is regulated by the Food and Drug Administration's Center for Devices and Radiological Health.

6. BRIEF DESCRIPTION OF CONTROL MEASURES – Describe the method(s) used to protect airspace; for example, termination on a building (where the beam path is not accessible by aircraft including helicopters), use of observers, use of radar and imaging equipment, physical methods of limiting the beam path, etc. The more the operation relies on the control measures to ensure safety, the more detailed the description should be.

7. ATTACHMENTS – In 7.(a) list the number of "Laser Configurations" you are submitting with this notice. If a particular setup operates with more than one laser, with different beam characteristics (power settings, pulse modes, divergence, etc.) or has multiple output devices (example: projector heads), then each should be analyzed as a separate laser configuration. In 7.(b) list all additional attachments that are included to assist the FAA in sufficiently evaluating the proposal, such as maps, diagrams and details of control measures.

8. DESIGNATED CONTACT PERSON – Specify the person with whom the FAA will communicate if additional information is needed. This should be the person most knowledgeable about laser safety of this operation. However, the person could also be the laser operation central contact that interfaces with the FAA. The designated contact person should work for or represent the proponent listed in 1.(b).

9. STATEMENT OF ACCURACY – The person having the authority to bind the proponent should sign the form.

10. WORKSHEET INSTRUCTIONS – See AC 70-1, Outdoor Laser Operations.

11. PAPERWORK REDUCTION ACT STATEMENT – The FAA intends to maintain a high level of safety between laser operations and aircraft operations. The FAA is requesting that laser operators submit information on a voluntary basis using the form listed. It will take the proponent approximately 10 hours to provide the necessary information for the initial system analysis. The time should decrease with subsequent submissions for the use of the same laser system by the same respondent. A person is not required to respond to an information collection request unless it displays a currently valid Office of Management and Budget (OMB) number. The OMB control number assigned this request is 2120-0662.

Sample of Form Submitted to FAA for Outdoor Laser Operations

Please Type or Print on This Form

Form Approved OMB No. 2120-0662

		Failure To Provide All Requested Information May Delay Processing of Your Notice		FOR FAA USE ONLY	
U.S. Department of Transportation Federal Aviation Administration		NOTICE OF PROPOSED OUTDOOR LASER OPERATION(S)			
1. GENERAL INFORMATION					
(a) To: (FAA Regional Office)			(b) From: (Proponent)		
(c) Event or facility			(d) Report Date:		
(e) Customer			(f) Site address		
2. DATE(S) AND TIMES(S) OF LASER OPERATION					
(a) Testing and alignment			(b) Operation		
3. BRIEF DESCRIPTION OF OPERATION					
4. ON-SITE OPERATION INFORMATION					
(a) Operator(s)					
(b) On-site phone #1			(c) On-site phone #2		
5. FDA CDRH LASER LIGHT SHOW VARIANCE (if applicable)					
(a) Variance #		(b) Accession #		(c) Expiration date	
6. BRIEF DESCRIPTION OF CONTROL MEASURES					
7. ATTACHMENTS					
(a) Number of laser configurations [fill out one copy of page 2 of this notice ("Laser Configurations Worksheet") for each configuration]					
(b) List additional attachments (including maps, diagrams, and details of control measures)					
8. DESIGNATED CONTACT PERSON (if further information is needed)					
(a) Name			(b) Position		
(c) Phone		(d) Fax		(e) E-mail	
9. STATEMENT OF ACCURACY					
To the best of my knowledge, the information provided in this Notice and attached worksheet(s) is accurate and correct.					
(a) Name (if different from contact person)			(b) Position		
(c) Signature			(d) Date		

Instructions for Completing Laser Configuration Worksheet**(modified from FAA Advisory Circular 70-1, Outdoor Laser Operations)**

(This form was current at the time of printing. Actual forms required by the FAA may be different.)

A single outdoor operation may have a number of lasers or “laser configurations” – power settings, wavelength, pulse modes, divergence, etc. In section 7.(a), of the Notice of Proposed Outdoor Laser Operations form, enter the number of different laser configurations for the outdoor operation. Then, complete one Laser Configuration Worksheet (page 2) for each different configuration.

Data sources: This form requires calculations based on data concerning the laser beam’s characteristics. The data can be obtained from direct measurement, manufacturer specifications, or specialized instruments. Also, data may be derived by making reasonable, conservative assumptions (e.g., that a certain value makes the beam more hazardous than it would be in reality). All data should err on the side of safety. In borderline situations where data accuracy is crucial to compliance, provide additional information on measurement techniques, data sources, and assumptions.

1. CONFIGURATION INFORMATION – In 1.(a), enter the number of the specific configuration and the total number of configurations. In 1.(b), enter the name of the event or facility. In 1.(c), enter the date the worksheet is prepared or sent to the FAA. In 1.(d), describe the beam projecting or directing system. Include a description of the site layout. Attach additional sheets if more space is required.

2. GEOGRAPHIC LOCATION – In 2.(a), enter the elevation of the site in feet above Mean Sea Level (MSL). In 2.(b), enter the height of the laser above the site elevation. This value should reflect the total height including any tall structure or building on which the laser may be located. In 2.(c), enter the total height of the laser above MSL (site elevation + height above site elevation). For aircraft or spacecraft operations, attach additional information on the flight locations and altitudes. In 2.(d) and (e), enter the latitude and longitude in degrees, minutes and seconds. Some maps or devices may give this information in “Degrees Decimal” form; convert this value into degrees, minutes, and seconds. In 2.(f), enter the method used to determine the latitude and longitude. In 2.(g), enter the horizontal datum used to determine the latitude and longitude. In 2.(h), enter the vertical datum used to determine the site elevation.

3. BEAM CHARACTERISTICS AND CALCULATIONS – Determine the mode of operation for this configuration: single pulse, continuous wave, or repetitively pulsed. Check the appropriate column and fill out only the beam characteristics, MPE calculations, and visual effect calculations applicable to that column.

4. BEAM DIRECTION(S) – Enter the maximum and minimum elevation angles. Also, provide the pointing directions and elevation angles (minimum and maximum) of the beam projections for this configuration only: If the beam is moved horizontally during the operation, enter the movement range under “Azimuth.” For example, “20° to 50°.” Make sure you give the range going clockwise, otherwise your data will be interpreted as directing the beam everywhere but where you intend. Specify if azimuth is in true or magnetic readings. Provide the magnetic variation for the location if this is known (necessary if you mark the “Magnetic” check box or if you are using a compass as part of your control measures).

For some configurations, additional information concerning the beam direction may be needed. For example: lasers that are very widely separated at the geographic location, or a laser used on an aircraft or spacecraft that is moving and/or shoots downward.

5. CALCULATED DISTANCES – There are four distances that are important in evaluating the safety of outdoor operations: For some visible pulsed lasers, the sensitive exposure distance, the critical exposure distance, or the laser-free exposure distance may be calculated to be less (shorter distance) than the NOHD. If this is the case, for safety reasons do not enter the distance numbers in the applicable block. Instead, enter that the distance is “less than NOHD.”

Sample of Form Submitted to FAA for Outdoor Laser Operations

Please Type or Print on This Form

Form Approved OMB No. 2120-0662

		Failure To Provide All Requested Information May Delay Processing of Your Notice		FOR FAA USE ONLY	
U.S. Department of Transportation Federal Aviation Administration		LASER CONFIGURATION WORKSHEET			
1. CONFIGURATION INFORMATION		(b) Name of event/facility:		(c) Report date:	
(a) Configuration number _____ of _____					
(d) Brief Description of Configuration:					
2. GEOGRAPHIC LOCATION					
(a) Site Elevation (ft. above Mean Sea Level)		(d) Latitude _____° (deg.) _____' (min.) _____" (sec.)		(e) Longitude _____° (deg.) _____' (min.) _____" (sec.)	
(b) Laser Height Above Site Elevation (ft.)		(f) Determined by: ☐ GPS ☐ Map (Quad) ☐ Other _____			
(c) Overall Laser Elevation (a + b)		(g) Horizontal Datum: ☐ NAD 27 ☐ NAD 88			
(h) Vertical Datum: ☐ NGVD 29 ☐ NAVD 88					
3. BEAM CHARACTERISTICS AND CALCULATIONS (check one Mode of Operation only, and fill in only that column)					
Mode of Operation	☐ SINGLE PULSE	☐ CONTINUOUS WAVE	☐ REPETITIVELY PULSED		
Laser Type (lasing medium)	(not applicable)				
Power Watts (W)		maximum power	average power		
Pulse Energy Joules (J)		(not applicable)			
Pulse Width Seconds (s)	(not applicable)	(not applicable)			
Pulse Repetition Frequency Hertz (Hz)		(not applicable)			
Beam Diameter @ 1/e points Centimeters (cm)					
Beam Divergency 1/e @ full Angle Milliradians (mrad)					
Wavelength(s) Nanometers (nm)					
(a) MAXIMUM PERMISSIBLE EXPOSURE (MPE) CALCULATIONS (will be used to calculate NOHD).					
MPE W/cm^2	(not applicable)				
MPE per pulse J/cm^2		(not applicable)			
(b) VISUAL EFFECT CALCULATIONS (will be used only for visible lasers [400-700 nm] to calculate SZED, CZED, and LFED)					
Pre-Corrected Power (PCP) Watts (W)	Pulse Energy (J) x 4	Maximum Power (from above)	Pulse Energy (J) x PRF (Hz) OR Average Power		
Visual Correction Factor (VCF) (Enter "1.0" or use Table 5)					
Visually corrected Power PCP x VCF					
4. BEAM DIRECTION(S)		Magnetic variation (degrees)			
Maximum elevation angle (degrees)		Azimuth ☐ True ☐ Magnetic			
Minimum elevation angle (degrees, where horizontal = 0°)		(degrees) _____			
5. CALCULATED DISTANCES (fill in all three columns)	SLANT RANGE (ft.)	HORIZONTAL DISTANCE (ft.)	VERTICAL DISTANCE (ft.)		
NOHD (based on MPE)					
*SZED (for 100 $\mu W/cm^2$ level)					
*CZED (for 5 $\mu W/cm^2$ level)					
*LFED (for 50 n W/cm^2 level)					
*If the laser has no wavelengths in the visible range (400-700 nm), enter "N/A (non-visible laser)" in all blocks. For visible lasers, if the calculated SZED, CZED, and/or LFED is less than the NOHD, enter "less than NOHD." than NOHD."					
6. CALCULATION METHOD ☐ Commercial software (print product name)					
☐ Other [(describe method (spreadsheet, calculator, etc.))					

Sample of Form Submitted to FAA for Outdoor Laser Operations**Suspected Laser Beam Incident Report**

This form may be used by local ATC or airline authorities to report a suspected laser beam exposure. When completed, the report should be forwarded to the competent authority as soon as possible for further investigation. Additionally, an anonymous report of a safety issue can be completed and submitted to the Aviation Safety Reporting System – website: <http://asrs.arc.nasa.gov>.

Name _____ Age _____

Position (pilot, co-pilot, controller, etc.) _____ Phone _____

Type of vision correction worn at time of incident (spectacles/contact lenses) _____

Type of aircraft _____

Aircraft ID or call _____

Date and time of incident (UTC) _____

Date and time report is being completed (UTC) _____

Environmental factors:

Weather conditions _____

VMC/IMC _____

Ambient light level (day, night, sunlight, dawn, dusk, starlight, moonlight, etc.) _____

Location of incident:

Near (aerodrome/city/NAVAID) _____

Radial and distance _____

Phase of flight _____

Type/name of approach or departure procedure _____

Heading/approximate heading if in turn _____

Altitude (AGL) _____ (MSL) _____

Aircraft bank and pitch angles _____

Angle of incidence:

Did the light hit your eye(s) directly or from the side? _____

Light description:

Color _____
Nature of beam (constant/flicker/pulsed) _____
Light source (stationary or moving) _____
Do you feel you were intentionally tracked? _____
Relative intensity (flashbulb, headlight, sunlight) _____
Duration of exposure (seconds) _____
Was the beam visible prior to the incident? _____
Position of light source (relative to geographical feature or aircraft) _____

Circle the window where the light entered the cockpit:

Left left-front center right-front right other _____
Elevation of the beam from horizontal (degrees) _____

Effect on individual:

Describe visual*/psychological/physical effects _____

Duration of visual effects (seconds/minutes/hours/days) _____
Do you intend to seek medical attention? _____

Note. - This is recommended if even minor symptoms were experienced.

Effect on operational or cockpit procedures: _____

*Examples of common visual effects:

afterimage. A transient image left in the visual field after an exposure to a bright light.
blindspot. A temporary or permanent loss of vision of part of the visual field.
flashblindness. A visual interference effect that persists after the source of illumination has been removed.
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. Glare lasts only as long as the bright light is actually present within the individual's field of vision.

Suspected Laser Beam Exposure Questionnaire

This questionnaire may be filled out by the competent authority during interviews with persons exposed to laser beams. This information will be used to aid in any subsequent investigation and provide important medical and statistical data for the review of regulatory and enforcement issues associated with new laser beam applications and threats to aviation safety. The completed form should be forwarded to the appropriate aviation authority as soon as possible.

1. Did anyone else see the light beam? _____
2. What was the color(s) of the light? _____

Did the color(s) change during the exposure? _____
3. Did the light come on suddenly, and did it become brighter as you approached it? _____

4. Was the light continuous or did it seem to flicker? _____

If it flickered, how rapidly and regularly? _____
5. Did the light fill your cockpit or compartment? _____
6. How would you describe the brightness of the light? _____

Was it equally bright in all areas or was it brighter in one area? _____
7. Did you attempt an evasive maneuver? _____

If so, did the beam follow you as you tried to move away? _____

How successful were you in avoiding it? _____
8. Do you know the source of the light emission? _____
9. Can you estimate how far away the light source was from your location? _____

Was the source moving? _____
10. What was between the light source and your eyes - windscreen, glasses, contact lenses, etc.? _____

Did any of these sustain damage by the light? _____
11. Was the light coming directly from its source or did it appear to be reflected off other surfaces? _____

Were there multiple sources of light? _____
12. Did you look straight into the light beam or off to the side? _____

13. How long was the exposure? _____

Did the light seem to track your path or was there incidental contact? _____

14. At what time of the day did the incident occur? _____

15. What was the visibility? _____

What were the atmospheric conditions - clear, overcast, rainy, foggy, hazy, sunny? _____

16. What tasks were you performing when the exposure occurred? _____

Did the light prevent or hamper you from doing those tasks, or was the light more of an annoyance? _____

17. What were the visual effects you experienced (after-image, blind spot, flash-blindness, glare*)? _____

18. How long did any symptoms you experienced from the exposure last? _____

Are any symptoms (tearing, light sensitivity, headaches, etc.) still present? _____

19. Did you touch or rub your eyes at the time of the incident? _____

20. Did you have your eyes examined after the incident? _____

If so, when and by whom? _____

What were the results of this visit? _____

21. Did you report the incident? _____

If so, to whom (ATC, medical personnel, safety officer, etc.) and when?

*Examples of common visual effects:

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

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

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

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. Glare lasts only as long as the bright light is actually present within the individual's field of vision.

Sample Notification Letter to FDA/CDRH

(This letter is an example of a notification letter to the FDA/CDRH once a variance has been granted. All names and places are intended to be fictitious, and any similarities are purely coincidental.)

Date: 1/1/99

Office of Compliance (HFZ-342)
Center for Devices and Radiological Health
2098 Gaither Rd.
Rockville, MD 20850

Ref: FDA/CDRH Docket No. 000-0000
Accession No. 0000000-0000

This is a notice of the following laser light show:

EVENT:	Fourth of July Festivities
VENUE:	Seattle Fairgrounds
TIME(S) AND DATE(S):	7/4/99 - 8:00 p.m. to 10:00 p.m.
EFFECT(S) UTILIZED:	Beams into sky
DESCRIPTION OF SHOW:	Beams in an outdoor environment
EQUIPMENT UTILIZED:	Laser Model XXX 20 W System
LASER OPERATOR(S) IN CHARGE OF SHOW:	John Doe
AGENCIES NOTIFIED:	FDA/CDRH and FAA
DESCRIPTION OF SAFETY FACTORS:	All pertinent safety factors will be adhered to: three meter rule, barriers, beam blocks, and use of certified laser projector.

MISCELLANEOUS COMMENTS:

If you have any further questions or comments, please don't hesitate to call me at (000) 555-0000.

Sincerely,

John Doe
Office Manager

Sample Letter of Objection from FAA

(This letter is an example. All names and places are intended to be fictitious, and any similarities are purely coincidental.)

Mr. John Doe
Laser Coordinator
John Doe Laser Co.
0000 North St.
Seattle, WA 00000

Dear Mr. Doe:

This letter is in response to your proposals for a laser show scheduled for July 4, 2000 at Seattle Fairgrounds, in Seattle, WA. An aeronautical study has been performed by this office regarding your request dated September 1, 1998 for a proposed laser light show at the Seattle Arena. Limitations on laser beam propagation into navigable airspace are necessary in order to integrate your show into the National Airspace System. The proposed site would be too close to the nearby Seattle Airport. That area is directly within the “laser-free zone” described in FAA Order 7400.2.

Therefore, the proposals are objectionable.

If you need further assistance, please contact me at (000) 555-0000.

Sincerely,

Tom Smith
Airspace and Procedures Manager

Sample Letter from FAA

(This letter is an example. All names and places are intended to be fictitious, and any similarities are purely coincidental.)

Mr. John Doe
Laser Coordinator
John Doe Laser Co.
0000 North St.
Seattle, WA 00000

Dear Mr. Doe:

This letter is in response to your proposals for a laser show scheduled for July 4, 2000 at Seattle Fairgrounds, in Seattle, WA. The proposed site would be close to the nearby Seattle Airport. Unterminated beams would enter the "laser-free zone" described in FAA Order 7400.2.

However, the FAA has no objection provided the laser beams are terminated on the grandstand building, as was stated in your letter. The termination area at the site must be large enough to stop the beams and allow for all pointing inaccuracies.

If you need further assistance, please contact me at (000) 555-0000.

Sincerely,

Tom Smith
Airspace and Procedures Manager

Sample Letter to Laser Clearinghouse Program

(This letter is an example. All names and places of the sender are intended to be fictitious, and any similarities are purely
coincidental.)

Date: 8/1/98

To:

North American Aerospace Defense Command
CMOC/J3
Attn: Orbital Safety Officer
Cheyenne Mountain Operations Center

From:

John Doe
Laser Manager
John Doe Laser Co.
1 North Main Street
Xville, XX 00000
(000) 555-0000
FAX (000) 555-0000

Subject: Laser Clearinghouse Program

This is a letter for approval for our upcoming laser operations scheduled on 1/1/99. Attached is our "Laser Clearinghouse Information Sheet." We hope that your evaluation of the attached information will conclude that our operations pose no threat to orbiting spacecraft. In the event that a Laser Clearinghouse screening shall be required, please let us know as soon as possible so that we may make the appropriate modifications in order to obtain Laser Clearinghouse approval. I can be reached at (000) 555-0000. Thank you for your time.

Sincerely,

John Doe
Attachment

Sample Laser Clearinghouse Information Sheet

(This form is an example of a notice once clearance has been granted by the Laser Clearinghouse.
Other information may be required by Space Command.)

Date: 1/1/99

This is a notice of the following outdoor laser operations:

LASER SITE:**SECTION 1:****Point of Contact**

Name:

Mailing Address:

Commercial Phones:

DSN Phones:

Secure Phones and Type:

FAX:

AUTODIN routing indicator

& plain language address:

SECTION 2:**Project Data**

Project Name:

Project Start Date:

Project Completion Date:

Typical Laser Target (check all that apply):

___ Look-angle

___ Missile

___ Star

___ Satellite

SECTION 3:**Site Geodetics**

Fixed Site:

Latitude:

Longitude:

Altitude:

SECTION 4:**Laser Parameters****CONTINUOUS WAVE LASERS**

Firing Mode:

Output Power:

Wavelength:

Divergence Half-Angle:

Operating Time:

Output Aperture Diameter:

Jitter Angle:

Strehl Beam Quality:

SECTION 5:**List of Targets**

Sample Letter of Acceptance from the Laser Clearinghouse Program

(This letter is an example. All names and places of sender and receiver are intended to be fictitious, and any similarities are purely coincidental. At the time of publication of this document, the telephone numbers of the Laser Clearinghouse were accurate.)

FROM: CMOC/J3 (Cheyenne Mountain Operations Center)

TO: John Doe
Laser Manager
John Doe Laser Co.
1 South Main St.
Xville, XX 00000

SUBJECT: Laser Clearinghouse Program

1. J30XA has evaluated the John Doe Laser System. This laser, as described below, does not exceed our damage threshold and will not require Laser Clearinghouse screening.

POWER:	0 W
WAVELENGTH:	0 μm
DIVERGENCE (HALF-ANGLE):	0 radians
TIME (duration of testing):	0 hours

2. Special Operations section in Cheyenne Mountain has granted the John Doe Laser Company an unconditional waiver of the laser described above. Please let us know if the laser parameters change; the laser becomes inactive; or if the John Doe Laser Co. adds or deletes a laser.

3. Please refer any questions to the Orbital Laser Safety Manager for Cheyenne Mountain, at (719) 474-4416 or fax (719) 474-3604.

Sincerely,

(Jack Brown)
Chief of Operations
Cheyenne Mountain Operations Center

Appendix B**Sample Calculations (Examples) for Specific Laser Systems****B1. General.**

Calculations and measurements are necessary for a hazard evaluation of outdoor laser systems. Each section of this appendix uses one set of laser parameters and several examples to illustrate various safety issues.

B2. Symbols.

The following symbols are used in the formulas of this appendix.

a = Diameter of emergent laser beam (cm)
 d_e = Diameter of pupil of eye (cm)
 D_f = Diameter of limiting aperture (cm)
 D_L = Diameter of laser beam (cm)
 D_e = Diameter of the exit pupil of an optical system (cm)
 D_{fp} = Beam diameter at the focal point of a lens (cm)
 D_0 = Diameter of objective lens of optical aid (cm)
 D_p = Diameter of beam on a target (cm)
 D_w = Diameter of beam waist (cm)
 E = Irradiance (W cm^{-2})
 f = Geometric focal length of a lens (cm)
 H = Radiant exposure (J cm^{-2})
 L_e = Radiance of an extended source ($\text{W cm}^{-2} \cdot \text{sr}^{-1}$)
 M = Magnifying power of an optical instrument
 MPL = Maximum permissible level (W cm^{-2}); may represent any interference level
 NOHD = Nominal ocular hazard distance (cm)
 NOHD-M = Nominal ocular hazard distance when magnifying optics are used (cm)
 Q = Energy per pulse from a pulsed laser (J)
 Φ = Radiant power emitted from a laser (W)
 PRF = Pulse repetition frequency (Hz)
 r = Range from laser to viewer (cm)
 r_1 = Range from a target to viewer (cm)
 s = Distance from an object to a focusing lens (cm)
 s' = Distance from a focusing lens to an image (cm)

t = Width of an individual pulse (s)

$T_{\max}$ = Maximum exposure duration (s)

α = Angular subtense of a laser source (rad)

$\alpha_{\min}$ = Maximum angle subtended by a small source (rad) (equal to 1.5 mrad)

$\alpha_{\max}$ = Angle beyond which hazards are related to radiance or integrated radiance (rad) (equal to 100 mrad)

Δ = Edge inaccuracy of an optical flat (cm)

ϕ = Emergent beam divergence (rad)

ϕ_d = Contribution to divergence of a reflected beam due to diffraction (rad)

ϕ_r = Divergence of a reflected beam (rad)

ϕ_s = Contribution to divergence of a reflected beam due to surface quality (rad)

ϕ_0 = Contribution to divergence of a reflected beam due to emergent beam divergence of beam striking a target (rad)

Φ_d = Power transmitted by an aperture (W)

Φ_0 = Total power in a laser beam (W)

λ = Wavelength of optical radiation (μm)

ρ_λ = Reflection coefficient from a surface at a particular wavelength

θ_v = Viewing angle measured from normal (perpendicular) to a reflecting surface (rad)

ω = Beam radius at $1/e^2$ of peak irradiance points (cm).

NOTE: For all calculations, values need to be converted to the basic units listed in the above definitions (e.g., cm, rad, W and J). However, these values are often referenced with modified units (e.g., m, mm, km, mrad, mW or mJ).

B3. Examples of Hazard Evaluation.

B3.1. Infrared Diode Pointer. A laser diode infrared pointer is used by police to identify criminals to other policemen using night vision goggles sensitive in the infrared. The laser's wavelength, λ , is $0.830 \mu\text{m}$, has an exit aperture of about 7 mm, and has a rated output power of 50 mW. Persons to be identified would generally be located beyond 50 m. What are the hazards and necessary controls?

Example 1. Find the MPE for unintentional viewing of a 0.830-μm laser.

Solution. Step 1. Determine if the laser is CW or pulsed. Even if the output appears continuous, the laser may be operating at a high pulse-repetition frequency. If the laser is pulsed, a lower MPE will result. The laser is determined to be CW by an oscilloscope. A detector sensitive to 0.830 μm with a rise time of 10 ns is used. Various settings of the oscilloscope revealed the absence of pulses up to a PRF of 55 kHz (the laser can be treated as CW).

Step 2. Determine the MPE. The MPE for unintentional exposure is usually based on a 10 s exposure duration unless other information would indicate a different exposure duration. From Table 2, we find that the MPE for an exposure duration between 18 μs and 10 s for lasers with wavelengths between 0.400 and 1.050 μm is provided by the equation:

$$MPE = 1.8 C_A t^{0.75} \times 10^{-3} \text{ J cm}^{-2}, \quad B1$$

where t is the exposure duration and C_A is the wavelength correction factor. The MPE for a 10 s exposure is $10.1 C_A \text{ mJ cm}^{-2}$, or simply $1 \times C_A \text{ mW cm}^{-2}$ when we divide by the 10 s exposure. The value of C_A is:

$$C_A = 10^{2(\lambda - 0.700)}, \quad B2$$

where λ is in micrometers (μm). For 0.830 μm, C_A is 1.82. The MPE is then 1.8 mW cm^{-2} for a 10 s exposure duration from this laser.

Example 2. Determine output power for the same laser.

Solution. Step 1. Select a detector. A radiometric detector with an active detector area 2 cm in diameter is selected for the measurement since the beam diameter is much smaller. Viewing the reflected energy from the detector allows the beam to be aligned with the center of the active area, and reveals that all the laser energy is contained within the active area. The detector is designed to measure thermal energy and has been recently calibrated. Since the instrument is thermal, the readings are essentially independent of wavelength and will accurately measure CW laser energy. A value of 45 mW is measured after the detector has reached thermal equilibrium. The laser is turned off and a zero reading is checked. The measurement is repeated for confirmation.

Step 2. Apply correction factors. Correction factors are built into this device, so no corrections are necessary.

Example 3. Determine beam diameter.

Solution. Step 1. Visual observation. The exit port of the laser is about 7 mm in diameter. When a spot is viewed on a matte target, the beam diameter appears somewhat smaller than 7 mm, and doesn't change with distance, at least for 2 or 3 meters.

Step 2. Measure through a 7-mm aperture. The 7-mm aperture will correspond to the energy that could enter a dark-adapted pupil diameter. A measurement with the aperture centered in the beam yields 35 mW. Therefore, 78% of the laser beam is transmitted through the aperture. For a Gaussian laser beam, 63% of the beam is transmitted through a circular aperture that is the same size as the beam diameter, measured at the 1/e points. The mode structure of the laser isn't known, but the beam diameter at 1/e points is probably less than the 7-mm measurement aperture. An approximation for beam diameter, based on a measurement through an aperture is:

$$D_L = \sqrt{\frac{-d^2}{\log_e (1 - f(d))}}, \quad B3$$

where d is the aperture diameter, and $f(d)$ is the fraction of the beam energy passed by the aperture. The beam diameter approximation for this laser is about 6 mm.

Example 4. Determine necessary optical density for protective eyewear.

Solution. Step 1. Worst case OD. The worst case (most conservative) protection is computed by assuming the entire output of the laser could enter a person's eye – in this case, it would be 45 mW. The OD is computed from the log of the ratio of the total output power to the Class 1 AEL. The Class 1 AEL is the product of the MPE and the area of the limiting aperture,

$$OD = \log_{10} \left(\frac{\Phi_0}{\text{Class 1 AEL}} \right). \quad B4$$

In this case, the maximum necessary OD is 1.8. This OD would protect a person at any distance whether or not optical viewing aids were used.

Step 2. Unaided viewing. Only 78% of the beam is transmitted through a 7-mm aperture, simulating the pupil of the eye. The $\log_{10}$ of $1/0.78$ is 0.11, which

can be subtracted from the 1.8 value above indicating that an OD of 1.7 is adequate.

Step 3. Optically aided viewing. An OD of 1.7 would be adequate since about 70% of the energy would be transmitted through optics due to internal reflection losses.

Example 5. Determine beam divergence.

Solution. Step 1. Visual observation. A path of 15 m is available to check the beam diameter along the beam path. Visual observation shows that the beam tends to increase in diameter along the beam so that the beam appears to be about 1 cm in diameter at the end of the 15 meters. No external beam waist is noted.

Step 2. Lens selection. A long focal length lens is chosen since little increase in beam diameter is noted after the 15-meter path. A high quality lens with a focal length of about 4 m is available. The precise focal length at 0.830 μm is not known, however, so a measurement needs to be designed to determine the lens focal length at this wavelength. A bright lamp with a visible filament is placed at 8 m from the lens. A narrow pass filter at 0.830 μm is placed in front of the filament. The image is then located at about 8 m on the other side of the lens with an infrared viewer. The image of the filament is found to be located at a distance of 7.42 m. The object distance is represented by s and the image distance is represented by s' . The geometric focal length, f , is then determined by the formula:

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}. \quad \text{B5}$$

For this lens, the focal length is 3.85 m at 0.830 μm .

Step 3. Measure the beam diameter at the geometric focal length of the lens. The laser beam diameter is measured by placing fixed apertures at 3.85 m from the center of the lens. An aperture of 1 mm in diameter centered in the beam passes 37% of the total beam energy, including transmission losses of the lens. The diameter at that location is then 1.5 mm. The beam divergence, ϕ , is then found by dividing the focused beam diameter, D_{fp} , by the focal length of the lens, f :

$$\phi = \frac{D_{fp}}{f}. \quad \text{B6}$$

By converting all measured values to centimeters before doing the calculations, the beam divergence is found to be 3.9×10^{-4} rad (0.39 mrad).

Example 6. Determine hazard class.

Solution. Step 1. Determine the most hazardous viewing condition. The worst-case viewing condition, considering both unaided and optically aided viewing, determines the hazard class. For unaided viewing, 78% of the laser energy passes through a 7-mm aperture simulating a dark-adapted pupil. For optically aided viewing all the laser energy is collected by a 50-mm aperture, however transmission losses within the optics reduces the transmission to 70%. Therefore, unaided viewing is the most hazardous viewing condition at close distances.

Step 2. Determine the AELs. The MPE for a 10-s exposure is 1.8 mW cm^{-2} . The Class 1 AEL is the MPE multiplied by the area of a 7-mm aperture (0.385 cm^2), or 0.7 mW. The Class 3R AEL is 5 times that or 3.5 mW. Since the output is 35 mW measured through a 7-mm aperture, but less than the Class 3B AEL of 500 mW, the laser is Class 3B.

Example 7. Determine nominal ocular hazard distance (NOHD) for unaided viewing and optically aided viewing.

Solution. Step 1: Unaided viewing. One formula for computing NOHD is:

$$\text{NOHD} = \frac{1}{\phi} \sqrt{\frac{-D_f^2}{\log_e \left(1 - \frac{\text{Class 1 AEL}}{\Phi_0} \right)} - a^2}, \quad \text{B7}$$

where Φ_0 is the total output energy without regard to any aperture, and D_f is the limiting aperture for the eye, which is always 7 mm in the retinal hazard region from Table 3. Substituting the measured values, the NOHD is 140 m.

Step 2. Optically aided viewing. Individuals in the area are known to be using 7 $\times$ 50 binoculars (7 power with 50-mm entrance aperture, 7.14-mm exit aperture). These binoculars have 70% transmission at 0.830 μm . A general formula for computing NOHD with optics is provided below:

$$\text{NOHD-M} = \frac{1}{\phi} \sqrt{\frac{-D_0^2 [\text{Min}(D_f, D_e)]^2}{D_e^2 \left[\log_e \left(1 - \frac{\text{Class 1 AEL}}{\Phi_0 \tau} \right) \right]} - a^2}, \quad \text{B8}$$

where D_0 represents the entrance aperture of the binoculars, D_e represents the exit aperture of the binoculars, and $\text{Min}(D_f, D_e)$ represents the minimum of the exit aperture of the binoculars and the limiting aperture for the eye. For this example, D_f is smaller

than D_e . Substituting and solving yields an NOHD-M of 840 m, ignoring atmospheric attenuation. Atmospheric attenuation has little effect on NOHDs shorter than 1 km.

Example 8. Determine the diffuse reflection hazard from a matte surface. Assume that the laser is located 1 m from the target and a minimum viewing distance of 20 cm.

Solution. Step 1. Determine angular subtense. The angular subtense, α , is the diameter of the beam striking the reflecting surface divided by the distance from the viewer's eye to the target. Since the beam diameter doesn't change in the first meter from this laser, the source angle is 6 mm divided by 20 cm, or 30 mrad.

Step 2. Determine the irradiance at 20 cm. The formula for determining the irradiance, E , from a perfect Lambertian diffuser is:

$$E = \frac{\rho_\lambda \Phi_0 \cos \theta_v}{\pi r_1^2} \quad B9$$

where ρ_λ is the target surface reflectance at 0.830 μm , Φ_0 is the laser power, $\cos \theta_v$ is a correction for off axis viewing, and r_1 is the viewer distance. $\cos \theta_v$ and ρ_λ are equal to 1.0 for a worst-case analysis. Substituting these values into B9 yields an irradiance of 36 $\mu\text{W cm}^{-2}$ at 20 cm.

Step 3. Determine the MPE. Considering only thermal effects for this wavelength, the MPE is the small source MPE multiplied by the extended source correction factor, C_E (see 8.2.2). This factor is the ratio of the angular subtense to the limiting angular subtense, $\alpha_{\min}$ (1.5 mrad). The value of C_E is thus 30/1.5 or 20. The corresponding MPE is 36 mW cm^{-2} at 20 cm from the diffuse target. There is no diffuse hazard since the irradiance is 1000 times less than the MPE.

Example 9. Determine optical density needed at the suspect's location, with and without the potential use of binoculars by the suspect.

Solution. Step 1. Calculate the beam diameter at 50 m. Since no external beam waist was observed, it can be assumed that the beam waist is located at the laser exit port (see Figure B1). It may, in fact, be located within the cavity or be external to the cavity as shown in Figure B2. Assuming that the waist is close to the exit port, the following formula provides a conservative estimate of beam irradiance as a function of range:

$$D_L = \sqrt{a^2 + r^2 \phi^2} \quad B10$$

Use of B10 indicates that the beam diameter at 50 m is 2 cm.

Step 2. Determine corneal beam irradiance averaged over the 7-mm pupil diameter. Since the beam diameter is about three times the pupil diameter, the average irradiance can be estimated from the peak irradiance. The peak irradiance can be calculated by:

$$E = \frac{1.27\Phi}{D_L^2} \quad B11$$

Use of B11 indicates that the peak irradiance is 14 mW cm^{-2} .

Step 3. Determine the OD for unaided viewing. The $\log_{10}$ of the ratio of the peak irradiance to the MPE provides the necessary OD. The MPE is 1.8 mW cm^{-2} and, therefore, the necessary OD at 50 m is about 0.9.

Step 4. Determine the OD for optically aided viewing. Since the beam diameter at 50 m is still much less than the collecting aperture of the binoculars, the OD of 1.7 has not changed from that necessary at the laser exit port. Using the gain factor of the optics would lead to erroneous results. An increase in true irradiance of 49 times would exist on the cornea, but the beam size on the cornea would be much smaller than the pupillary diameter. An OD of 2.4 would be indicated by straight computation; however, no more laser power can enter a person's eye than that emitted by the laser.

Step 5. Determine the usability of the device. Since laser eyewear will not be supplied to the suspects, the laser is too powerful to be used in this application. However, a filter could be purchased to reduce the laser power to the point that the MPE is not exceeded at the suspect's location. The NOHD needs to be reduced from 140 m to less than 50 m.

A rule of thumb is that the NOHD is proportional to the square root of the output laser power. A 10% transmitting filter is available, which would reduce the NOHD to about 44 m. This filter would reduce the laser output power to 4.5 mW. When the NOHD is checked with the equations from Example 7, the actual NOHD is determined to be 41 m for unaided viewing. An NOHD of 140 m is probably too long for the operator to control the beam safely in an urban setting. An operator-controlled laser generally has an NOHD of no more than 100 m. A Class 3R laser with a maximum output power of 3.5 mW would probably be better suited for this task.

B3.2. Military Laser System. The laser is a rangefinder/designator, tripod mounted, Q-switched

Nd:YAG laser operating at 1.064 μm , with an output energy per pulse of 100 mJ, a beam diameter of 4.5 cm at 1/e peak irradiance points, and a beam divergence of 0.07 mrad, also measured at 1/e points. The PRF is about 10 Hz.

Example 10. Determine the MPE for an unintentional exposure for the pulsed YAG laser.

Solution. Step 1. Determine the MPE for a single pulse. From Table 5, the MPE for a Q-switched laser (pulse width less than 50 μs) at 1.064 μm is 5 $\mu\text{J cm}^{-2}$.

Step 2. Determine the MPE for exposure to multiple pulses. For a 10 s exposure to this laser, an individual could be exposed to as many as 100 pulses. The repetitive pulse correction factor, C_p is $n^{-0.25}$, where n is the total number of pulses in the exposure. For 100 pulses, this factor is 0.32. The MPE for each pulse in the train of 100 pulses is then 1.6 $\mu\text{J cm}^{-2}$.

Example 11. A test of the laser system involves aiming the laser at a target located 50 m downrange. Determine the hazard at the laser transmitter from a specular reflection from the target. The specular target is a 1 cm diameter flat glass cover for an instrument.

Solution. Step 1. Determine the energy striking the specular reflector (see Figure B3). The beam diameter, D_L , at 50 m can be determined from the following equation:

$$D_L = \sqrt{a^2 + r^2 \phi^2} \quad \text{B12}$$

where a is the initial beam diameter. For this laser, D_L is about 4.51 cm at 50 m from the laser (little change from the diameter at the laser exit port). Since the target is only 1 cm in diameter, less than 5% of the total power will strike the reflector. The following equation provides the laser power that will be transmitted through an aperture, d , from a Gaussian beam when the beam diameter at 1/e points is known:

$$\Phi_d = \Phi_0 \left(1 - e^{-\frac{d^2}{D_L^2}} \right) \quad \text{B13}$$

This formula can also be used to determine the energy that will impact on the reflector by substituting Q for Φ . In this case, 4.8% or about 4.8 mJ per pulse impacts the mirror.

Step 2. Determine the energy reflected from the glass. Normal glass will reflect about 4% per surface

when the beam strikes at normal (90°) incidence. A two-surface reflection will reflect about 8%. The reflected energy, Q_r , per pulse is thus about 0.38 mJ and the radiant exposure near the target is then 480 $\mu\text{J cm}^{-2}$, or about 300 times greater than the MPE.

Step 3. Determine the reflected beam divergence. The reflected beam divergence consists of several parts (see Figure B4):

(1) initial beam divergence. Since the beam has not changed significantly in the first 50 m, the reflected beam divergence should be about the same as the initial beam divergence, ϕ_0 (70 μrad).

(2) effect of reflector size. The beam divergence is also limited by the diameter of the aperture divided by the laser to target distance (200 μrad). Since this value is greater than 70 μrad , the initial beam divergence would take precedence.

(3) diffraction effect. Since the reflector is so small, diffraction would affect the reflected beam divergence. The divergence due to diffraction, ϕ_d , is approximately

$$\phi_d = \frac{1.22\lambda}{2D_p}, \quad \text{B14}$$

where D_p is the diameter of the reflector in this case. The contribution due to diffraction is 65 μrad , based on λ of 1.064×10^{-4} cm and a reflector diameter of 1 cm.

(4) surface curvature. Even an optical flat would have some curvature and surface imperfections, which could affect the divergence. The surface was specified as flat to 1/4 wavelength, and the contribution to divergence by the surface, ϕ_s , could be as much as

$$\phi_s = 16 \frac{\Delta}{D_p}, \quad \text{B15}$$

where Δ is the edge inaccuracy, which in this case is 1/4 of the helium-neon wavelength used to test the glass cover. One fourth of 0.6328 μm is 1.6×10^{-5} cm, and 16Δ is 2.5×10^{-4} cm. The surface could contribute about 250 μrad to the reflected divergence. This effect should be measured since it is the most dominant contribution.

The sum of all the contributions to the reflected divergence, ϕ_r can be approximated by

$$\phi_r = \sqrt{|\phi_0 + \phi_s|^2 + \phi_d^2} \times \text{sign}(\phi_0 + \phi_s), \quad \text{B16}$$

where ϕ_r could be either positive or negative, depending on the surface curvature. In this case the sum of all contributions yields an estimated beam divergence of about 330 μrad .

Step 4. Calculate the radiant exposure at 50 m from the reflected beam. The energy per pulse is 0.38 mJ, the initial beam diameter is 1 cm and the reflected beam divergence is 330 μrad . When the beam diameter is much larger than the pupillary diameter, the NOHD may be calculated as follows:

$$\text{NOHD} = \frac{I}{\phi_r} \sqrt{\frac{1.27 Q_r}{\text{MPE}} - D_p^2}. \quad \text{B17}$$

The reflected beam is therefore estimated to be hazardous at distances up to 530 m back from the reflector. Personnel at the laser source would need to wear eye protection, and personnel behind and to the sides would also need to be protected. The easiest method for protection may be changing the flat cover of the detector to one with a curved surface.

Example 12. Determine the specular hazard at the laser transmitter from a reflection from a tank view block that is 15 cm high by 30 cm wide and located 1 km from the laser transmitter. An observer is located next to the laser transmitter and observing the target with 7×50 binoculars. The tank vision block has been tested and observed to add an additional 70 μrad of divergence due to surface curvature.

Solution. Step 1. Determine the reflected energy. The beam diameter, D_L , at 1 km is about 8.3 cm. The tank vision block is larger than the beam; therefore, the entire beam could strike the reflector. Since the surfaces of the vision block are not parallel, only one surface enters into the calculation. Four percent of the energy per pulse is 4 mJ.

Step 2. Determine the reflected beam divergence from multiple contributions (see Figure B4).

(1) Original beam effect. Since the reflector is larger than the laser beam, the contribution from the original beam is the same as the initial beam divergence (0.07 mrad).

(2) Diffraction effect. Diffraction, ϕ_d , is based on the beam size at the reflector (8.3 cm). This contribution is about 7.8 μrad .

(3) Surface curvature effect. The surface curvature contribution is 70 μrad .

(4) Summing the contributions. Since diffraction has little effect, the divergence of the reflected beam is about 140 μrad .

Step 3. Calculating reflected NOHD. The following equation can be used to determine the reflected NOHD:

$$\text{NOHD} = \frac{I}{\phi} \left[\sqrt{\frac{1.27 Q_r \rho_\lambda}{\text{MPE}}} - D_p \right] \quad \text{B18}$$

where ρ_λ is the reflection coefficient at 0.830 μm . These assumptions indicate that the reflected beam could be hazardous to 3.4 km from the reflector that is located 1 km from the laser. Operators of the laser should wear laser eye protection if the vision block cannot be removed.

Step 4. Determine the size of the reflected beam at the operator's position. The beam diameter is the diameter at the target plus the expansion.

$$D_L = D_p + r_1 \phi_r \quad \text{B19}$$

The beam diameter of the reflected beam is then 22 cm at the operator's position.

Step 5. Determine radiant exposure at the operator's position from the reflected beam.

The radiant exposure in the center of a Gaussian beam is

$$H = \frac{1.27 Q_p}{D_L^2} \quad \text{B20}$$

The radiant exposure from the reflected beam is then 10.5 $\mu\text{J cm}^{-2}$ at the laser transmitter. The necessary OD for unaided viewing is:

$$\text{OD} = \log_{10} \left(\frac{H}{\text{MPE}} \right). \quad \text{B21}$$

Since the MPE is 1.6 $\mu\text{J cm}^{-2}$, an OD of 0.82 is needed for unaided viewing. Except for transmission losses, the radiant exposure through 7×50 binoculars on the cornea is increased by about 49 times, or an OD of 1.7. For 10×50 binoculars, the increase is about the same as for 7×50 binoculars since the objective lens is the same diameter. The transmission of binoculars at this wavelength is about 70%, resulting in a decrease in necessary OD of 0.15. These ODs may be added to determine the needed OD for 7×50 binoculars, which is 2.4.

Example 13. Determine optical density needed for someone located 50 m to the left of the target and viewing the target with 7×50 binoculars. Assume that the specular reflector could be inadvertently oriented to direct the reflected beam in that direction.

Solution. Step 1. Determine reflected power.

Part 1. Parallel reflection coefficient. The following provides the percentage of reflection for a beam that has its electric vector parallel to the reflecting surface.

$$\rho_{\parallel} = \frac{\tan^2(\theta - \theta')}{\tan^2(\theta + \theta')} \quad \text{B22}$$

where θ is the angle of the incident laser beam normal to the reflecting surface, and θ' is the refraction angle. For this example, the incidence angle is 45° so that the full angle between the incident beam and the reflected beam is 90° .

Although the angle of refraction would not normally be of concern, it is necessary for computing the reflected power. From Snell's law, the angle of refraction on an air to glass interface depends on the index of refraction of the glass:

$$\theta' = \sin^{-1}\left(\frac{\sin \theta}{n}\right) \quad \text{B23}$$

Normal glass has a refractive index of about 1.5. Therefore, the refraction angle is about 28° . The parallel reflection coefficient is about 0.9%.

Part 2. Perpendicular reflection coefficient. This percentage is provided by:

$$\rho_{\perp} = \frac{\sin^2(\theta - \theta')}{\sin^2(\theta + \theta')} \quad \text{B24}$$

The perpendicular component is then about 9.3%.

Part 3. A measurement using a separate Brewster window and an optical detector reveals that the laser is not polarized. The reflected beam energy is then about 5.1% of 100 mJ or 5.1 mJ.

Step 2. Determine reflected beam divergence. The horizontal dimension of the vision block appears smaller at the operator's location since it is turned at an angle. However, the projected image is still over 21 cm wide. The vertical dimension is unchanged. The reflected divergence is the same as from Ex. 12.

Step 3. Determine the beam diameter at the viewer's location. The initial reflected beam diameter increases by $r \phi$ or 0.7 cm. The beam diameter is then 9 cm.

Step 4. Determine the radiant exposure values. The radiant exposure is then $80 \mu\text{J cm}^{-2}$.

The hazards to the side of the reflector are about 28% greater than those from Example 12, which amounts to an additional OD of 0.11.

B3.3. Laser Light Show. A laser light show operator plans to use a 40 W Argon laser (mixture of $0.488 \mu\text{m}$ and $0.514 \mu\text{m}$ wavelengths) near a small airport with one active runway. The exit beam diameter of the laser is about 1 mm and the divergence is 7.5 mrad at the $1/e^2$ of peak irradiance points. The show is located about 5 miles directly to the side of the active runway. The desired angles of operation are 360° in azimuth and 0° to 90° in elevation. What precautions are necessary?

First, both the FDA/CDRH and the FAA need to be convinced that the show will not present a hazard to flight operations before the show will be approved. The proper paperwork (letters from the FDA/CDRH, FAA and an SOP) needs to be on hand before turning on the laser. All required safety equipment needs to be available. Safety observers need to be available, properly trained, and posted. The show will also probably have to be customized to fit the environment.

Example 14. What modifications will be necessary for the laser light show to satisfy the requirements of the FDA/CDRH and the FAA?

Solution. Step 1. Make a drawing before making any conclusions (see Figure B5).

Step 2. Just from the diagram, it would be prudent to limit the azimuth of the beam to avoid the laser-free zone. There is plenty of other space to operate the laser light show.

Example 15. What would the local irradiance be at the edge of the laser-free zone?

Solution. Since several Government agencies are involved, many different units are used. All the provided values have to be converted to a common set of units before calculations can be performed. Converting all quantities to metric seems most logical.

Table B1. Units Conversion Table.

Provided unit	Metric Equivalent
Nautical Mile (NM)	1.85 km
Statute Mile (mile)	1.61 km
10,000 feet	3.05 km

Since each nautical mile (NM) is 1.85 km, the laser-free zone extends 3.7 km from the center of the

runway, toward the location of the light show. The show is 5 statute miles or 8.05 km from the runway center. Therefore, the edge of the laser-free zone is 4.35 km from the laser location. The irradiance, E , at the center of a laser beam may be estimated by the formula

$$E = \frac{1.27\Phi}{a^2 + r^2\phi^2}, \quad \text{B25}$$

where Φ represents the laser power, ϕ represents the beam divergence at $1/e$ of peak irradiance points, a represents the initial beam diameter, and r is the distance from the laser. The divergence provided is at $1/e^2$ of peak irradiance points. A simple conversion to a $1/e$ divergence, based on a Gaussian beam shape is to divide the $1/e^2$ divergence by the square root of 2. The divergence in terms of the $1/e$ points (necessary for safety calculations) is thus 5.3 mrad. The irradiance is then about $9.6 \mu\text{W cm}^{-2}$ at the border to the laser-free zone.

Example 16. What are the MPE and other applicable visual interference levels?

Solution. The MPE for wavelengths between 0.4 and $0.7 \mu\text{m}$ is 2.55 mW cm^{-2} for a 0.25 s exposure. At the boundary of the laser-free zone, the irradiance of $9.6 \mu\text{W cm}^{-2}$ is less than the MPE by a factor of about 270. The visual interference level (in terms of effective irradiance) that is allowed in the laser-free zone is 50 nW cm^{-2} .

A visual response value is selected from Table 1. A precise photopic luminous efficiency factor may be determined from a spectral breakdown of the laser. However, an easier method is to assume that the entire output is at $0.5145 \mu\text{m}$ (worst case). The relative visual response for this wavelength is about 0.6 from interpolation of Table 1. The effective irradiance for the laser is then $5.7 \mu\text{W cm}^{-2}$. The effective laser irradiance exceeds the laser-free level by over 100 times. Therefore, the azimuth or elevation probably should be adjusted to avoid the laser-free zone, altogether. Further computations may show that airplanes landing would only be in the beam for such a short time that, perhaps, the beam would not interfere with vision.

The critical level is $5 \mu\text{W cm}^{-2}$. The effective irradiance at the laser-free border is slightly greater than the critical level; however, the laser is actually sitting in the critical zone. The laser may be able to operate, however, if safety observers or other means are used to ensure that no aircraft are exposed within the applicable visual interference zones.

Example 17. How would the MPE and effective irradiance change if a 40-W, frequency doubled, Q-switched, Nd:YAG laser, pulsed at 20 kHz, were substituted for the Argon laser?

Solution. Both the MPE and effective irradiance would change. The MPE would be reduced since the laser is no longer continuous, but consists of Q-switched pulses at a rate of 20 kHz. However, the light would appear continuous. From Table 4, the MPE is 47% of the CW MPE for visible lasers (0.4 to $0.7 \mu\text{m}$) with a 20 kHz PRF. The MPE is therefore about 1.2 mW cm^{-2} instead of 2.5 mW cm^{-2} .

The effective irradiance also changes due to the change in wavelength from $0.5145 \mu\text{m}$ to $0.532 \mu\text{m}$. From Table 1, the relative photopic visual response is about 0.88, resulting in an effective irradiance of $8.5 \mu\text{W cm}^{-2}$. The effective irradiance would not be affected by the laser being pulsed, rather than continuous wave.

Example 18. What are the NOHD and other protection distances from Ex. 16?

Solution. From Equation B26, the protection distances (PDs) to the various levels can be determined:

$$\text{PD} = \frac{1}{\phi} \sqrt{\frac{1.27\Phi}{\text{MPL}}}, \quad \text{B26}$$

where PD represents any of the ocular hazard distances (including NOHD, sensitive exposure distance, critical exposure distance, laser-free exposure distance), Φ represents the actual laser power for NOHD calculations and effective power for visual interference distances, and MPL represents any of the hazard levels (MPE, sensitive level, critical level, or laser-free level). These calculated distances in Table B2 are corrected for atmospheric attenuation by using Table C1.

Table B2. Protection Distances for Example 17.

Type of Ocular Hazard	Protection Level ($\mu\text{W cm}^{-2}$)	Protection Distance (m)	Corrected Protection Distance (m)
NOHD	2600	266	266
Sensitive	100	1,345	1300
Critical	5.0	6,014	5,300
Laser-free	0.05	60,014	29,000

Example 19. What protective procedures are necessary for this show?

Solution. Since the laser-free protection distance is so large, it would probably be best to avoid having the laser beam cross any portion of the laser-free zone near the airport by limiting the operating azimuth. Since the critical protection distance is 5.3 km (2.9 NM), a safety observer could be positioned to observe the sky for aircraft that could intercept the laser beam. If this distance had been greater than 3 NM (5.5 km), other protective means would have to be instituted. Safety observers are only appropriate for laser light shows of limited duration. The elevation of the beam would need to be adjusted such that no one is exposed close to the laser beam while driving an automobile or observing from a window in any nearby tall building.

Since the laser output power exceeds 5 mW, a variance from the FDA/CDRH is required, and a letter of non-objection should also be obtained from the FAA. An SOP that outlines the protective procedures that have been implemented for this particular show, and identifies the responsible individuals that will see that these procedures are followed is also necessary.

B3.4. Laser Light Show Beacon. A laser light show operator plans to use a single beam from the combination of two, 20 W Argon/Krypton lasers (0.488, 0.5145, and 0.647 μm laser lines) as a beacon near a small airport with one active runway. The local FAA has designated a sensitive zone near some mountain peaks north of the runway. The exit beam diameter of the laser is about 5 mm and the divergence is 1.4 mrad at $1/e^2$ of peak irradiance points. The show is located about 24 km (15 miles) directly to the east at the end of the runway. The desired angles of operation are 0° to 360° in azimuth and static 15° in elevation. The beam will be operated from dusk to dawn every night. The beam will be scanning at a uniform rate of about one revolution every minute.

The FDA/CDRH and the FAA need to be convinced that the beacon will not present a hazard to flight operations before the beam can be turned on. The proper paperwork (letters from the FDA/CDRH, FAA and SOP) should be on hand before turning on the laser. In addition, all required safety equipment must be available.

Example 20. What type of airspace is affected by the operation?

Solution. Drawings quickly show the airspace that is affected. Figure B6 illustrates potential conflicts between using the laser beacon and possible interference with a local airport. Figure B7 is an overhead view of the same airport and laser demonstration (show) to the side.

Example 21. What would the local irradiance be at the edge of the critical and laser-free zones?

Solution. Step 1: The critical zone extends 18.5 km (10 NM) from the end of the runway. The show is 24 km (15 statute miles, or 13 NM) from the runway end. The edge of the critical zone is then 5.5 km (3 NM) from the laser location. The irradiance, E , at the center of a laser beam may be estimated by the formula:

$$E = \frac{1.27\Phi e^{-\mu r}}{a^2 + r^2\phi^2}, \quad \text{B27}$$

where $e^{-\mu r}$ accounts for absorption by the atmosphere. The atmospheric transmission factor may be obtained from Table C3. For a path length of 5.5 km, the atmosphere would transmit about 76% of the beam on a clear day (60 km visibility, assuming $\mu = 5 \times 10^{-7} \text{ cm}^{-1}$). The divergence provided corresponds to the $1/e^2$ of peak irradiance points. A simple conversion to a $1/e$ divergence yields 1.0 mrad. The irradiance is about $128 \mu\text{W cm}^{-2}$ at the border to the critical zone.

Step 2: The laser-free zone extends 9.25 km (5 NM) from the end of the runway. The show is then about 14.75 km from the edge of the laser-free zone. At this distance, the irradiance is about $5.3 \mu\text{W cm}^{-2}$ when attenuation by the atmosphere is taken into account.

Example 22. How does the beam irradiance compare to the MPE?

Solution. Step 1: The MPE for visible wavelengths (0.4 to 0.7 μm) is 2.55 mW cm^{-2} for a 0.25 s exposure duration. However, a pilot would be expected to receive an exposure less than 0.25 s. The actual expected exposure duration needs to be calculated. The beam diameter at 5.5 km would be about:

$$\begin{aligned} D_L = r\phi &= 5.5 \times 10^5 \times 1.0 \times 10^{-3} \\ &= 550 \text{ cm} = 5.5 \text{ m}. \end{aligned} \quad \text{B28}$$

Step 2: The circumference of the circle that is projected on the ground where the beam is scanning is:

$$C = 2\pi r = 2 \times 3.14 \times 5.5 \times 10^5 \text{ cm} = 35 \text{ km.} \quad \text{B29}$$

Since the beam is making one revolution every minute, the speed of the beam at the edge of the critical zone is 35 km/minute or 583 m s^{-1} . Since the beam diameter is about 5.5 m, the exposure duration is about $(5.5 \text{ m}) / (583 \text{ m/s}) = 9.4 \text{ ms}$. The MPE for 9.4 ms found from Table 2 is $1.8 \times C_A \times T_{\text{max}}^{-0.25} \text{ mW cm}^{-2} = 5.8 \text{ mW cm}^{-2}$. The actual irradiance at this location is less than the MPE.

Example 23. How does the effective irradiance compare to the visual interference levels?

Solution. Step 1: Additional information is required to determine visual effects. If the additional information is not available, a worst-case assumption is to set the visual response function from Table 1 to 1.0. For this laser, it was found that the emission was divided up among the wavelengths as follows:

Table B3. Laser Output Power.

Laser Wavelength (μm)	Percent of output power	$V(\lambda)$
<0.480	10	0.14
0.488	40	0.19
0.5145	20	0.60
0.647	30	0.13

An effective visual response function may be found by combining the visual stimulus from each wavelength by the percentage of the output at each wavelength. The $V(\lambda)$ for 480, 488, 514.5, and 647 may be combined by:

$$V(\lambda) = \sum_i V(\lambda_i) \times \% \text{Power} / 100 \quad \text{B30}$$

The effective $V(\lambda)$ is then about 0.25. The effective irradiance is then $0.25 \times 5.8 \text{ mW cm}^{-2} = 1.4 \text{ mW cm}^{-2}$.

Step 2: The sensitive level is $25 \mu\text{J cm}^{-2}$ for an exposure duration less than 0.25 s. For a 9.4 ms exposure, the level is $(25 \mu\text{J cm}^{-2}) / (9.4 \text{ ms}) = 2.66 \text{ mW cm}^{-2}$ (about the same as the MPE). Since the effective irradiance is compared with the sensitive level rather than the actual irradiance, the MPE indicates the greater hazard.

If the sensitive zone is 5.5 km or more from the laser location, the MPE takes precedence over the sensitive level.

Step 3: The critical level is $5 \mu\text{W cm}^{-2}$ averaged over a 0.25 s exposure duration. For 9.4 ms, the critical level is $1.25 \mu\text{J cm}^{-2}$ or 0.13 mW cm^{-2} . The critical level is much less than the MPE. Therefore, the actual irradiance divided by the MPE will be less than the effective irradiance divided by the critical level. The critical level then represents a greater hazard than the MPE.

Step 4: The laser-free zone is located 9.25 km (5 NM) farther from the laser location. The beam diameter at this location is 14.8 m at the edge of the laser-free zone. The circumference of the circle is 93 km. The speed of the beam at this location is then $93 \text{ km} \cdot \text{min}^{-1}$ or 1.5 km s^{-1} . The duration of the exposure is then $14.8 \text{ m} / 1.5 \text{ km} = 9.5 \text{ ms}$. The duration of the exposure has not changed, but the irradiance is reduced. The irradiance is then $23 \mu\text{W cm}^{-2}$ at this location. The laser-free level is $12.5 \text{ nJ cm}^{-2} = 1.3 \mu\text{W cm}^{-2}$ for a 9.5-ms exposure duration. The effective irradiance is $23 \mu\text{W cm}^{-2} \times 0.25 = 5.75 \mu\text{W cm}^{-2}$. The effective irradiance exceeds the laser-free level at the edge of the laser-free zone.

Example 24. What is the NOHD of the laser?

Solution. By ignoring the initial beam size, the duration of exposure is constant with viewing distance from the rotating beam. The NOHD may then be calculated by B31, which is derived from B27:

$$\text{NOHD} = \frac{1}{\phi} \sqrt{\frac{1.27\Phi}{\text{MPE}}} = 940 \text{ m.} \quad \text{B31}$$

When the beam is stationary, the laser is more hazardous and the NOHD is 1.4 km.

Example 25. What limitations and precautions are necessary?

Solution. A scanning safeguard is necessary to terminate the laser beam when it stops scanning since the hazards would be increased for a stationary beam.

Since the irradiance exceeds both the critical and laser-free level, a beam mask could be used to prevent the laser beam from entering these zones. The NOHD of the laser is less than 1 km (which is less than 3 NM or 5.5 km). A safety observer can therefore be used to monitor airspace during initial testing of the device, providing that the observer has

a clear view. However, since the planned use of the device is for the entire night and 7 days a week, a safety observer could not be relied upon for such lengthy observation.

Once the laser beacon is in place, radar or other electronic monitoring equipment should be used to detect aircraft. A radar that is co-aligned with the laser beam could be used to monitor aircraft that would enter the beam within the NOHD. A prudent measure would be to cease operation any time that the radar picked up a plane within its detection range, which could be considerably longer than 3 km. The elevation of the beam would need to be adjusted such that no one is exposed close to the laser beam while driving an automobile or observing from a window in a tall building.

Example 26. Does the laser produce a diffuse reflection hazard?

Solution. Since the laser beam is several watts, exposure to the diffusely reflected beam at close distances is probably also hazardous (see Figure B8). From Table 7, a 40 W laser with a 5-mm beam diameter would not produce a diffuse viewing hazard for a momentary (0.25 s) exposure, even at 20 cm viewing distance. However, from Table 7, a 10 s exposure to a 3 watt laser produces a diffuse reflection hazard. Therefore, this laser certainly produces a hazard during any type of alignment procedure.

Example 27. Does the laser produce a skin hazard?

Solution. From Table 6, the skin MPE for a 10 s exposure is 200 mW cm^{-2} . Near the laser exit, the irradiance from this laser is over 200 W cm^{-2} . Skin protection is in order, as well as, protective glasses.

Example 28. What paperwork is required?

Solution. Since the radiant power of the laser exceeds 5 mW, a variance would need to be obtained from the FDA/CDRH and a letter of non-objection should be obtained from the FAA. An SOP would also need to be written, which outlines the protective procedures that have been implemented for this particular show, and the responsible individuals that will see that these procedures are followed. The precautions are intended to protect both the public and the operator of the show.

B3.5 Scientific Experiment. A scientist plans to use a 1000 W CO_2 laser to scan the sky near a major airport. The exit beam size of the laser is about 1 m and the divergence is 0.075 mrad at $1/e^2$ of peak

irradiance points. The laser is located about 5 miles (8 km) directly to the side of the airport. The desired angles of operation are 360° in azimuth and 0° to 90° in elevation. Time of operation is from 6 a.m. to 6 p.m.

The FAA should be convinced that the experiment would not present a hazard to flight operations before work can begin. The proper paperwork (letter of non-objection from the FAA and SOP) should be on hand before turning on the laser. In addition, all required safety equipment as outlined in the SOP need to be available. Properly trained safety observers should be posted, or electronic surveillance should be available. The test will have to be customized to fit the environment.

Example 29. What precautions are necessary?

Solution. Make a drawing of the site (see Figure B9).

A safety observer would only be effective to no more than 5.5 km (3 NM). If the operation will occur during daylight, an observer may not be able to locate aircraft even at this distance. Before 3 NM is assumed as a reasonable distance for locating aircraft in this particular setting, some tests should be performed. If the airport is a military airport, stealth type aircraft or other operations may be performed with aircraft with subdued lighting, making the aircraft more difficult to spot.

Example 30. What would the local irradiance be at 5.5 km (3 NM) from the laser?

Solution. The irradiance, E , at this distance may be estimated by B25. The divergence provided corresponds to the $1/e^2$ of peak irradiance points. The divergence at the $1/e$ points is then 0.053 mrad (53 μrad) and the corresponding $1/e$ exit beam diameter is 71 cm. Due to the small divergence, the irradiance at 3 NM (5.5 km) is 217 mW cm^{-2} . This value is only 15% less than the irradiance at the output, 255 mW cm^{-2} . This value is more than twice the 100 mW cm^{-2} MPE based on a 10 s exposure duration. However, airplanes flying through the beam would not be exposed for 10 s. Since the beam is invisible, visual interference is not a hazard, but the MPE should not be exceeded. Since $10.6 \mu\text{m}$ optical energy does not penetrate most materials, personnel inside commercial aircraft would not be exposed in excess of the MPE. Personnel who would be at risk are skydivers, balloonists, and personnel flying in aircraft with no windows, such as helicopters with the side doors open.

Example 31. What is the MPE for this laser?

Solution. The MPE for far infrared wavelengths is 100 mW cm^{-2} for an exposure lasting 10 s or more. The MPE applies to both eye and skin exposure. No visual interference levels would apply since the beam is invisible. The MPE is higher for shorter exposures. The MPE for a short exposure from Table 2 is:

$$MPE = 0.56 \cdot T_{\max}^{-0.75} \text{ W cm}^{-2} \quad \text{B32}$$

The time that a person can be exposed without exceeding the MPE can then be found by solving the above equation for $T_{\max}$:

$$T_{\max} = \left(\frac{0.56}{MPE} \right)^{1.33} = \left(\frac{0.56}{0.217} \right)^{1.33} = 3.5 \text{ s.} \quad \text{B33}$$

If the beam moves to a new location every 3.5 s, then a stationary person will not be exposed above the MPE. Using B12, the beam diameter at 5.5 km is 77 cm. Since people may be moving somewhat, the beam should move a little faster. Persons exposed in this environment would not be expected to be moving too fast, except in the case of free-fall. Moving the beam by one diameter (77 cm) every 3.5 s is equivalent to 22 cm/s. At a distance of 3 NM (5.5 km), this rate of speed would correlate in angular measure to $40 \mu\text{rad/s}$ ($8.25^\circ/\text{hr}$). Therefore the scan speed should be maintained greater than $8.25^\circ/\text{hr}$. This precaution would ensure that no skydivers or other exposed personnel would be exposed in excess of the MPE at a distance that is outside the area where aircraft could be reliably seen by a safety observer. Electronic surveillance (such as radar or CCD camera equipment) may be used to spot aircraft at farther distances, if necessary.

Example 32. Determine NOHD from this laser.

Solution. The NOHD can be determined from B31 as follows:

$$\text{NOHD} = \frac{1}{\phi} \sqrt{\frac{1.27\Phi}{MPE}} = 21 \text{ km.} \quad \text{B34}$$

Without scanning, the NOHD is 21 km, based on a 10 s exposure duration. When this calculated distance is corrected for atmospheric attenuation by using Table C1, it is reduced to 14.6 km.

Example 33. What protective procedures are necessary from this laser?

Solution. Since NOHD based on a 10 s exposure is so large, it would probably be best to avoid having the laser beam stationary or touching any building within the 3 NM (5.5 km) that the safety observer is monitoring. A scanning safeguard may be necessary to ensure that the laser beam will be terminated should the scanning be interrupted. The elevation of the beam would need to be adjusted such that no one is exposed while standing on the ground or observing from a window in a tall building.

A letter of non-objection should be obtained from the FAA, since aircraft will be potentially exposed. An SOP would need to be written that outlines the protective procedures that have been implemented for this particular operation, and lists the responsible individuals that will see that these procedures are followed.

B3.6. Astronomy Experiment. A scientist plans to use a collimated 10 W Optical Parametric Oscillator (OPO) laser tuned to $0.589 \mu\text{m}$, as a guide star for astronomical observations. The laser is not near a major airport. In fact, the laser is located in a remote area on the top of a mountain. A military base is close by, but is not used much. The exit beam size of the laser is about $15 \text{ cm} \times 15 \text{ cm}$ and the divergence is about $4 \mu\text{rad}$ and focused. The desired angles of operation are 0° to 360° in azimuth and 10° to 90° in elevation.

The FAA needs to be convinced that the laser will not present a hazard to flight operations before work can begin. The proper paperwork (letter of non-objection from the FAA and SOP) should be on hand before turning on the laser. In addition, all required safety equipment must be available, and properly trained safety observers or electronic surveillance should be available. In addition, clearance should be obtained from the Laser Clearinghouse to ensure that the operation does not interfere with satellites. Coordination with the local military authority is also advisable.

A safety observer would usually only be effective to no more than 3 nautical miles (NM). However, in this remote area, observers may be able to spot aircraft at much longer distances. Before observers are relied on for locating aircraft in this particular setting, some tests should be performed. If the operation is near a military base, stealth type aircraft or other operations may be performed with aircraft with subdued lighting, making the aircraft more difficult to spot.

Example 34. What are the hazards?

Solution. Since the beam is collimated and focused, the local beam irradiance would not change much anywhere that aircraft could be located, except for atmospheric attenuation. Therefore, there is no point in computing an NOHD. The irradiance is about $(10 \text{ W})/(225 \text{ cm}^2) = 44 \text{ mW cm}^{-2}$. High-flying commercial jets would be traveling at about 600 mph. This speed would correspond to about 966 km/hr or 268 m/s. The exposure duration of a commercial pilot flying through the beam is then $15 \text{ cm}/(2.7 \times 10^4 \text{ cm s}^{-1}) = 560 \text{ } \mu\text{s}$. From Table 2, the MPE for this wavelength is:

$$\begin{aligned} \text{MPE} &= 1.8 \times 10^{-3} \times T_{\text{max}}^{-0.25} \text{ W cm}^{-2} \\ &= 12 \text{ mW cm}^{-2} \end{aligned} \quad \text{B35}$$

The irradiance of 44 mW cm^{-2} exceeds the MPE by about 4 times. For planes flying at a lesser speed, the MPE could be exceeded by a greater degree since the plane would remain in the beam longer.

The laser beam does not cross any critical zones or laser-free zones; however, it is conceivable that the FAA could assign a sensitive zone near the base of operation. The sensitive exposure level is $100 \text{ } \mu\text{W cm}^{-2}$ averaged over a 0.25 s exposure duration. Since the actual exposure (T_{max}) is less than 0.25 s, the sensitive level in terms of radiant exposure from Table 5 is $25 \text{ } \mu\text{J cm}^{-2}$, unless the MPE is lower.

For a laser pulse lasting $560 \text{ } \mu\text{s}$, the effective irradiance that would exceed the sensitive exposure level is $(25 \text{ } \mu\text{J cm}^{-2})/(560 \text{ } \mu\text{s}) = 45 \text{ mW cm}^{-2}$. The effective irradiance is determined from the actual irradiance by multiplying by the visual response function listed in Table 1. The closest wavelength in the table is $0.590 \text{ } \mu\text{m}$. Interpolation yields a visual response factor of 0.77. The effective irradiance is then $(44 \text{ mW cm}^{-2}) \times (0.77) = 34 \text{ mW cm}^{-2}$. The irradiance does not exceed the sensitive exposure level even when the visual response function is not applied. Therefore, the MPE takes precedence over the sensitive level. In this case, exceeding the MPE is the issue and not visual interference.

Example 35. What protective devices are available?

Solution. The beam will only be used during clear weather, so electronic viewing devices should be able to identify aircraft to an altitude of more than 60,000 ft. If the electronic devices are not capable of detecting aircraft at such long distances, it is possible that the power of the laser could be reduced by 4 times. Lower flying (and slower) aircraft should

still be protected. These aircraft could be expected to be flying at a minimum rate of 100 mph or 45 m s^{-1} . The exposure duration would then be about 3.3 ms.

The corresponding MPE is about 7.5 mW cm^{-2} . The output power of the laser would then have to be reduced by about 6 times. Otherwise, an array of CCD cameras could be installed to identify low flying aircraft before they entered the beam. Safety observers standing in the freezing cold weather does not seem to be a viable option.

Example 36. What elements should be included in a safety SOP?

Solution. This safety SOP should include the following items:

- Communication with base operations.
- Hours of operation.
- Laser hazards.
- CCD camera equipment available.
- Computer system necessary to monitor CCD cameras.
- Checkout procedure to make sure that CCD camera data is correct.
- Procedures to use during safety equipment malfunctions.
- Minimum configuration of safety equipment that will permit operation.
- Weather conditions necessary to permit operation.
- Special requirements from the Laser Clearinghouse.

Example 37. What paperwork should be on site?

Solution. A letter of non-objection should be obtained from the FAA, since aircraft will be potentially exposed. An SOP would need to be written that outlines the protective procedures that have been implemented for this particular operation, and the responsible individuals that will see that these procedures are followed.

A letter from the Laser Clearinghouse should be available stating that the operation will not interfere with satellites. Correspondence from the local military should be available stating that the laser will not endanger military troops during maneuvers.

B4. Specific Control Measures Examples.**B4.1 Military Laser.**

Example 38. What specific safeguards should be built into a Class 4, Airborne Laser Target Designator/Range finder designed for the Military?

Solution. First, check section 10 for specific requirements. Some requirements that can be satisfied are listed below:

1. At least two of the following interlocks should be installed:

(a) A “weight on wheels” switch, which enables firing of the laser only while airborne.

(b) A sensor that monitors air speed independent of wind speed and indicates when the aircraft is definitely airborne.

(c) An altimeter signal that indicates a preset above ground altitude has been achieved.

(d) For rotary winged aircraft, rotor activation conditions unique to airborne conditions.

2. A safe built-in-test and boresight operation on the ground and in flight. The laser is in a stowed position during this test to prevent external open beams.

3. To prevent inadvertent laser activation during flight, a master arm switch that enables the laser and weapons, and a laser arm switch that has to be pulled up and out and held until it latches. This arm position is held magnetically while safety interlocks are engaged, but springs back to safe position when interlocks are interrupted.

4. Software would need to prevent the laser from firing when slewing the system from one target to another. This feature will be tested during flight.

5. A training mode will allow simulated operations with a nonhazardous laser system. A visual indication will inform the pilot of the current operating mode, and when the laser is actually firing.

6. Laser ports are clearly identified, and laser-warning labels in subdued colors are present on the aircraft near the laser exit port. Specific laser warnings to the pilot are located in the cockpit.

B4.2. Handheld Laser Range finder.

Example 39. What safeguards should be built into a Class 3B handheld laser range finder used by police?

Solution. First, check section 4.3 of this standard, and 21 CFR 1040.10 and 1040.11. Some requirements and solutions are listed below:

1. A separate power switch and laser arm switch in addition to a single pulse activation switch for obtaining range. The system is tested for double pulsing and extraneous beams emitted from the exit port.

2. A built-in, opaque lens cover, which has been tested to ensure that it does not transmit laser energy at the laser wavelength. The cover should contain a visible indication when it is in place.

3. Eye protection filters that are built into the optical aiming sight, which contains a lighted reticule for use both in daytime and at night. The reticule is calibrated to identify proper buffer areas.

4. Separate emission indicators that are located within the sighting optics that indicate when the laser is armed and when it is actually firing.

5. When batteries are removed, all capacitors are discharged to prevent inadvertent activation of the device.

B5. Subnanosecond Pulses.

A scientist plans to use a collimated doubled Nd:YAG laser (0.532 μm) to track satellites. The laser has an output energy per pulse of 50 mJ and is pulsed at 5 Hz, with a pulse width of 200 ps. The laser is near major airports, and military bases are close by. The exit beam diameter of the laser is about 15 cm and the divergence is about 50 μrad . The desired angles of operation are 0° to 360° in azimuth and 10° to 90° in elevation.

The FAA should be convinced that the laser would not present a hazard to flight operations before work begins. The proper paperwork (letter of non-objection from the FAA and SOP) should be on hand before turning on the laser. In addition, all required safety equipment should be available, as well as properly trained safety observers or electronic surveillance. In addition, clearance should be obtained from the DoD Laser Clearinghouse to ensure that the operation does not interfere with other satellites.

Example 40. What are the hazards for biological injury?

Solution. The MPE for exposure to a 200 ps pulse is $2.7 C_A t^{0.75} \text{ J cm}^{-2}$. For this laser, the MPE is $1.44 \times 10^{-7} \text{ J cm}^{-2}$. For an unintentional exposure, a person would not be expected to receive more than two pulses. No wavelength correction would apply and the repetitive pulse correction would be 0.84. The MPE is then $1.2 \times 10^{-7} \text{ J cm}^{-2}$ for repetitive pulses. At the output of the laser, the radiant exposure is

about 0.28 mJ cm^{-2} , which is 2300 times the MPE. The Class 1 AEL is 46 nJ. The NOHD determined from Equation B7 is 146 km. Since the beams are pointed up through the atmosphere, little reduction in radiant exposure would result from atmospheric absorption.

Example 41. What are the hazards for visual interference?

Solution. A person could be exposed to two laser pulses within a normal aversion response of 0.25 s. The critical level is $5 \mu\text{W cm}^{-2}$, or $1.25 \mu\text{J cm}^{-2}$ for a 0.25 s exposure, or in this case, $6.25 \times 10^{-7} \text{ J cm}^{-2}$ per pulse. This level is 5 times higher than the MPE. The MPE would then take precedence over the visual interference effect in the critical region.

However, the laser-free level is lower than the MPE. Therefore, the laser presents a greater biological hazard than a visual interference hazard except in the laser-free zone.

Example 42. What safeguards could be used?

Solution. A prudent measure would be to prevent the laser beam from entering the laser-free zone of any neighboring airport. A safety observer would usually only be effective to no more than 3 miles. Since the NOHD of this laser is 146 km, a boresight radar is used to prevent aircraft from crossing the beam path during tracking. In addition, safety observers are used to prevent low-flying aircraft, which may be out of the detection area of the boresight radar, from crossing the beam path.

Coordination with the local military authority is also advisable if the beam will cross military controlled airspace. If the operation is near a military base, the use of stealth type aircraft or other operations may be performed with aircraft having subdued lighting, making the aircraft more difficult to spot and the safety observers less effective.

B6. References.

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Van De Merwe, W. P., and Marshall, W. J., "Hazardous Ranges of Laser Beams and their Reflections from Targets," *Appl. Opt.* 25(5). 605-611 (1986).

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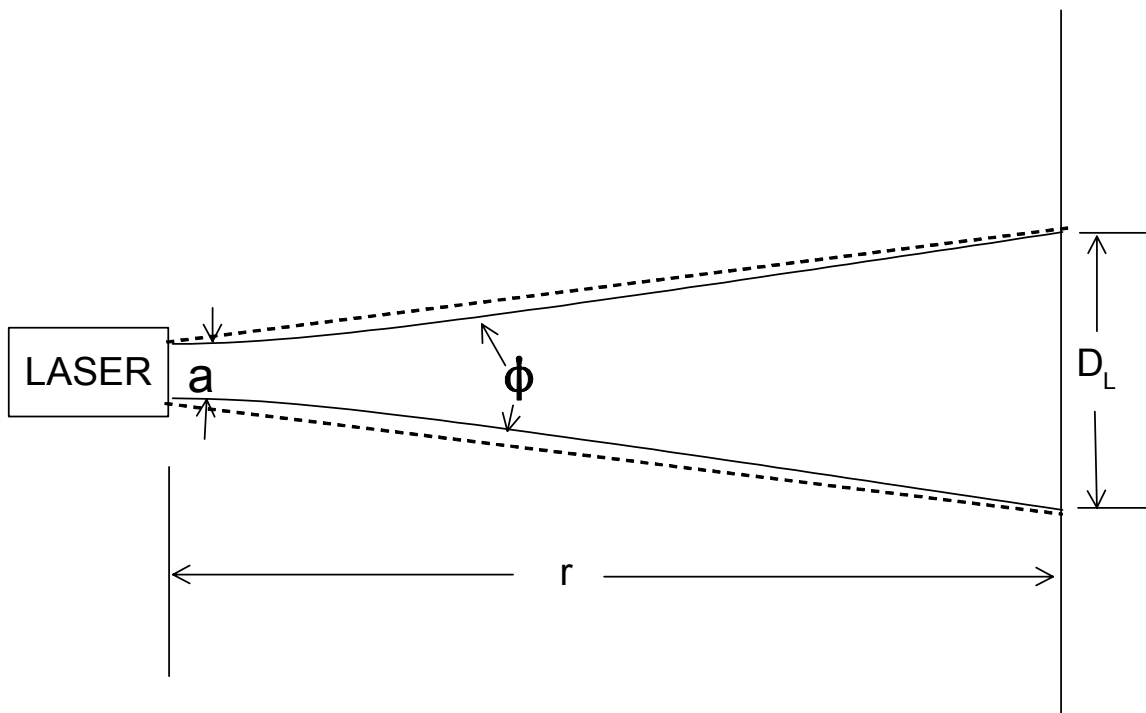


Figure B1. Expansion of a Laser Beam. When the beam waist is located near the laser exit port, the curved lines represent Gaussian beam expansion.

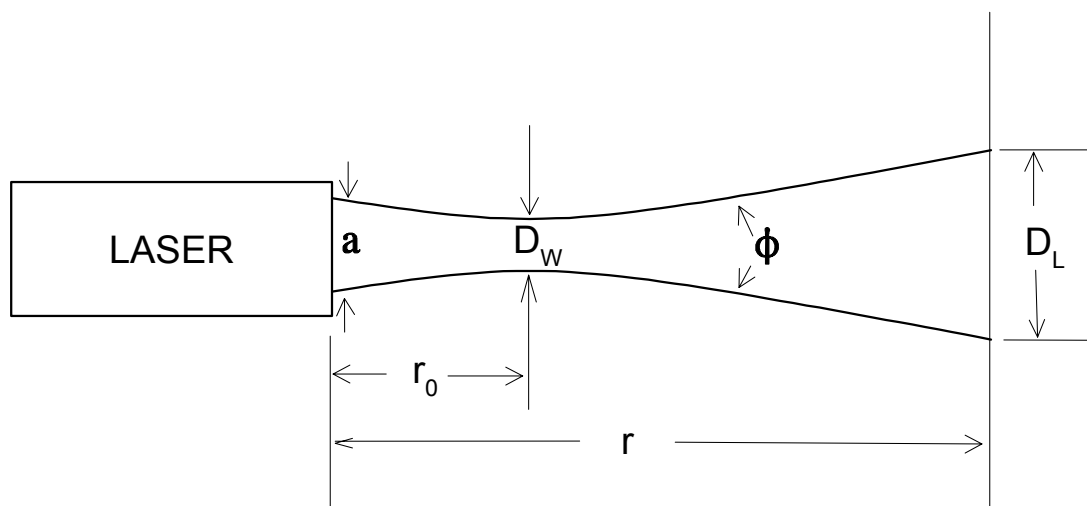


Figure B2. Laser Beam Expansion when Laser Beam has an External Beam Waist.

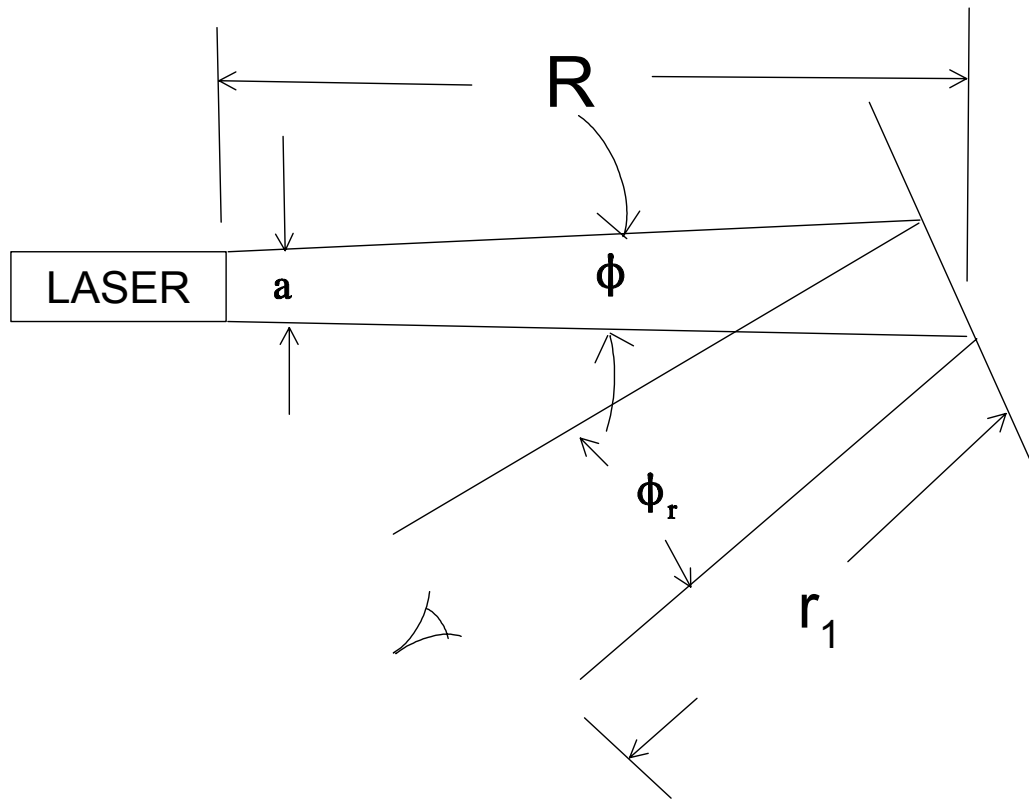
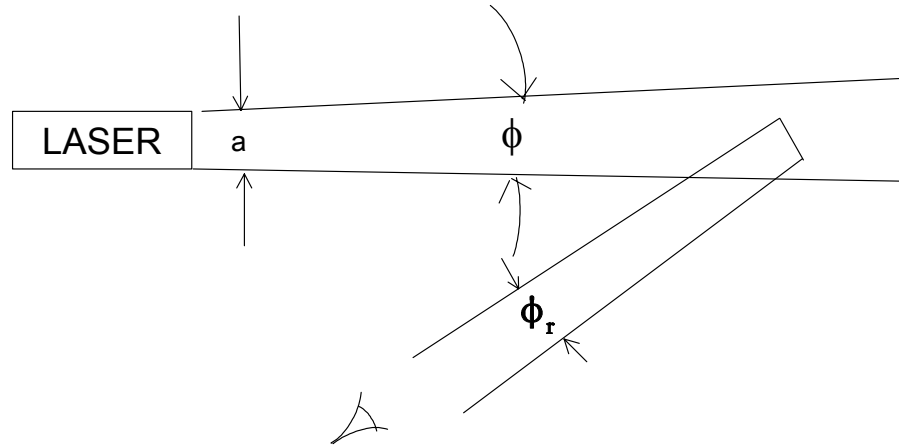
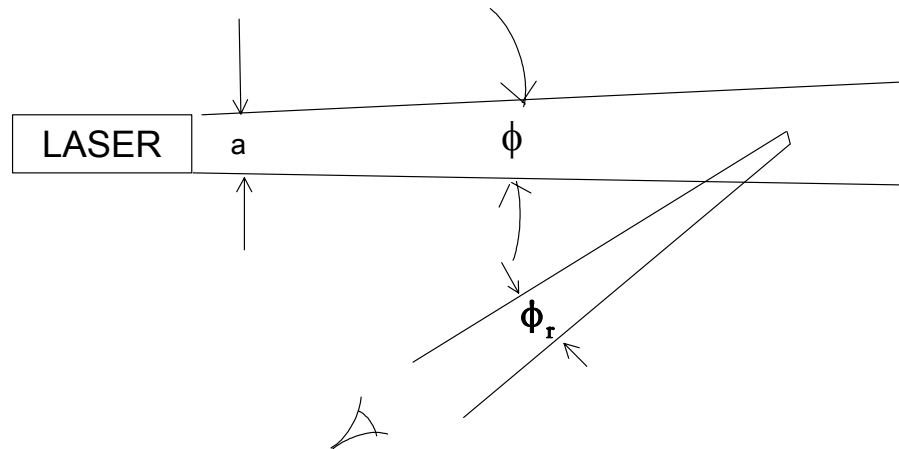


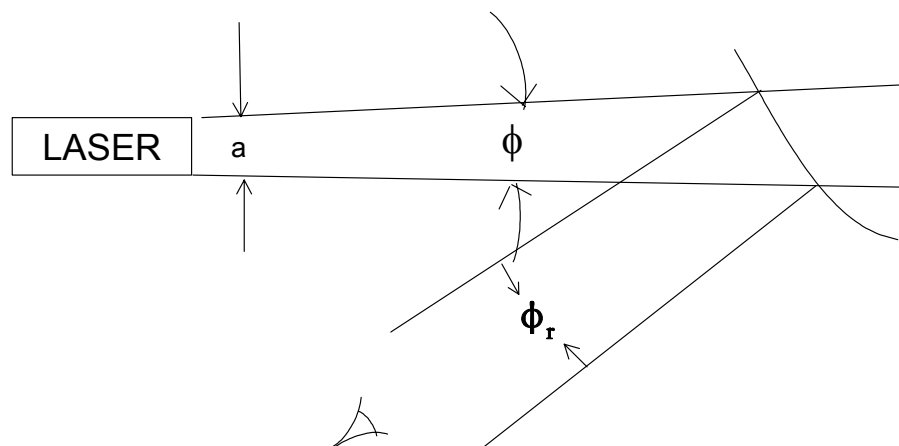
Figure B3. Specular Reflection of a Laser Beam. When the reflecting surface is large in comparison to the laser beam and very flat, the reflected beam divergence closely matches the divergence of the incident beam. Reflections from other surfaces are illustrated in Figure B4.



a. Reduced divergence due to reflector that is smaller than beam size.



b. Increased divergence due to diffraction effects from very small reflector size.



c. Increased or decreased divergence due to imprecise surface curvature.

Figure B4. Factors that Affect the Divergence of a Reflected Laser Beam.

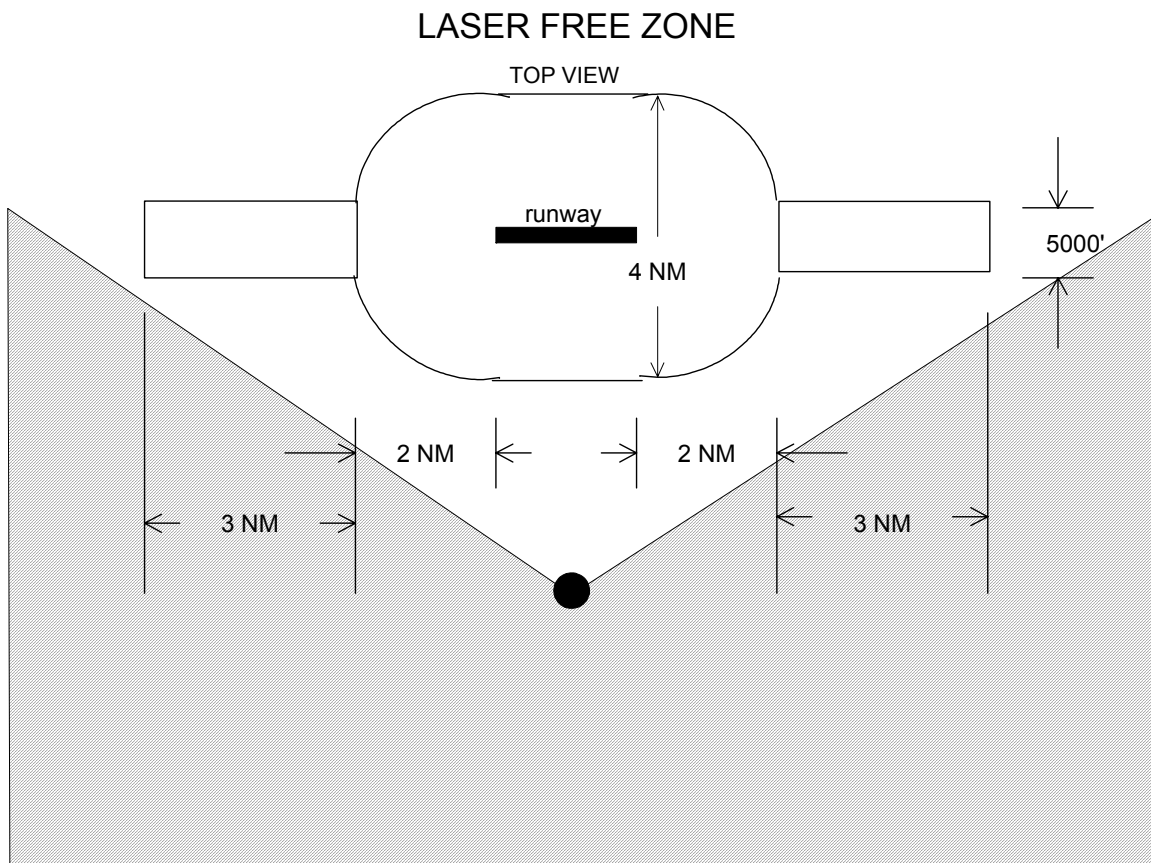


Figure B5. Drawing of Possible Beams from Laser Light Show near Airport.

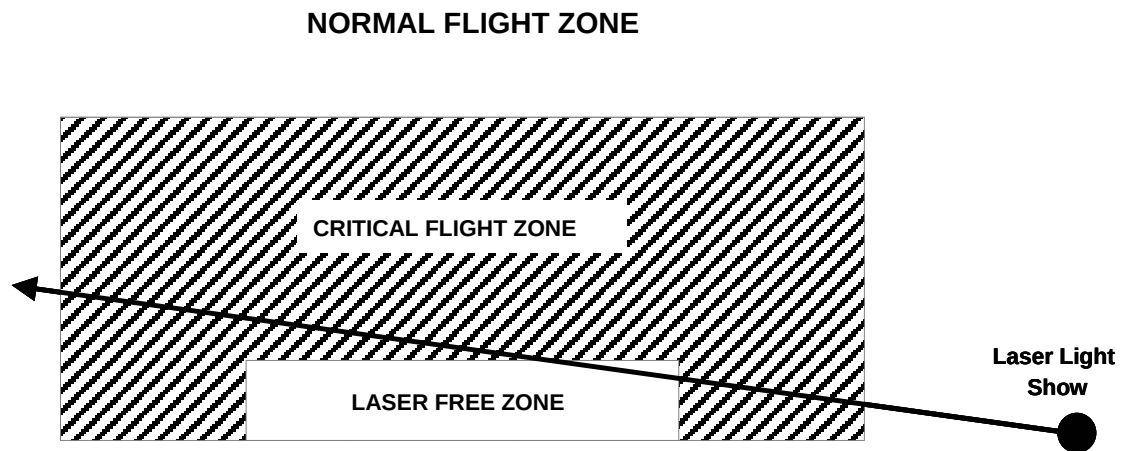


Figure B6. Drawing of Laser Beacon near Airport (Side View).

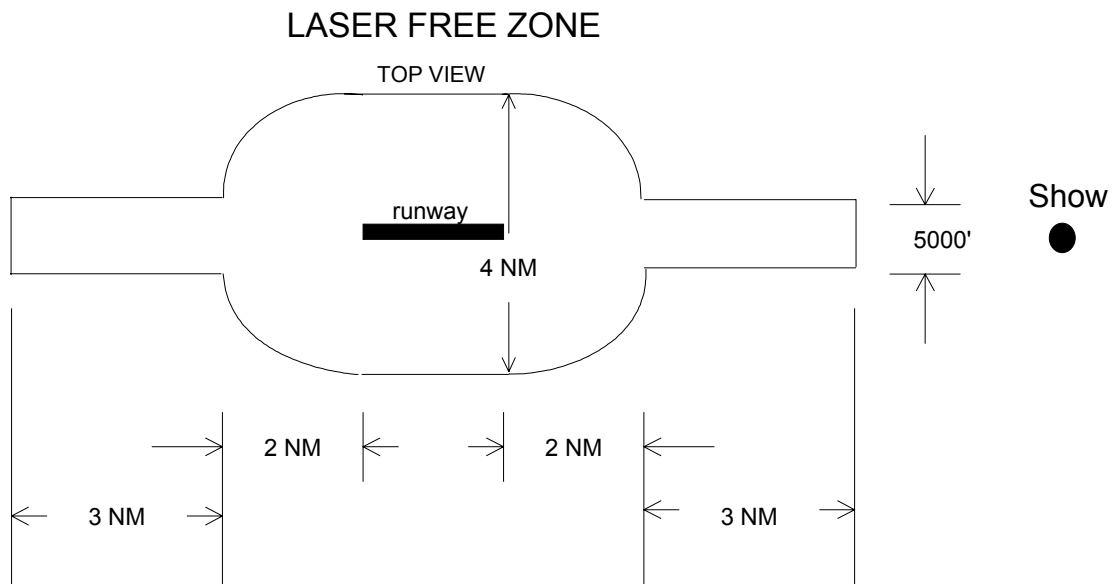


Figure B7. Drawing of Laser Beacon near Airport (Top View).

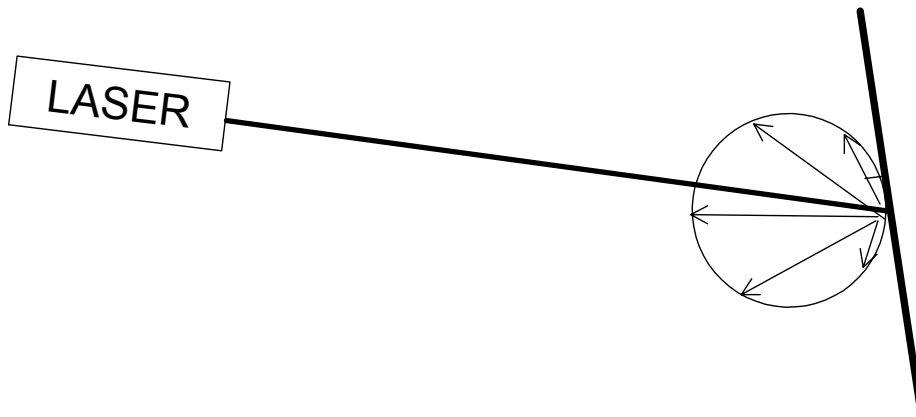


Figure B8. Diffuse Reflection of Laser Beam. The reflected laser energy is spread over a large area from a matte surface.

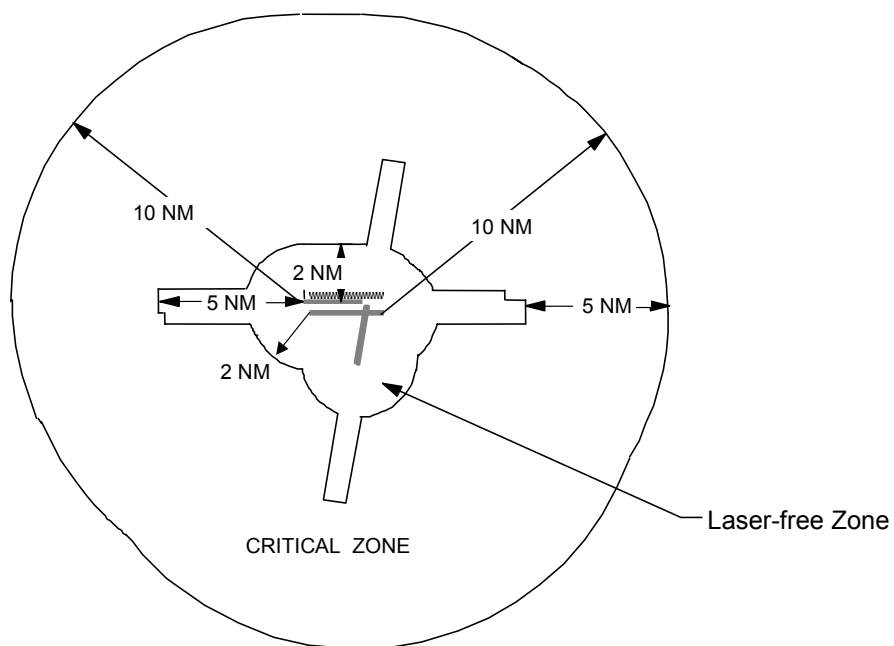


Figure B9. Rough Drawing of local Airport, Considering Feasibility of a Nearby Scientific Experiment.

Appendix C

Atmospheric Propagation

C1. Atmospheric Attenuation.

A laser beam that propagates through a vacuum will not be attenuated as it passes through space. However, under normal atmospheric conditions, the effect of atmospheric attenuation may become a major factor in evaluating the radiant exposure or irradiance at distances greater than a few kilometers from a laser. This attenuation consists of three effects: Mie and Rayleigh scattering and molecular absorption. Mie (or large particle) scattering occurs where the particle size is greater than the wavelength of the optical radiation, and is normally the greatest contributor in the visible and near infrared. Rayleigh (or molecular) scattering occurs where particle size is much less than the wavelength, is reasonably constant for a given wavelength, and is the greatest contributor in the ultraviolet. Absorption by gas molecules is normally insignificant in comparison to scattering and may therefore be disregarded except in the infrared.

Attenuation due to scattering is much more pronounced at shorter wavelengths; thus red light from a long wavelength visible laser is scattered far less than the energy from a laser that operates in the blue end of the visible spectrum. A clean atmosphere may therefore be expected to be relatively transparent to visible and near infrared wavelengths. If the effects of atmospheric attenuation are to be considered, knowing the meteorological range V (km) is necessary. The attenuation is usually based upon a V of 60 km or "Standard Clear Atmosphere" since the visibility may not be known during an outdoor operation.

C2. Atmospheric Scintillation.

As a laser beam passes through any real atmosphere, it may undergo localized changes in irradiance or radiant exposure as a result of passing through a portion of the atmosphere of varying index of refraction. These "turbulons" are created when temperature gradients produce variations in air density perpendicular to the beam propagation direction. Since this is a statistical process, probabilities are assigned to describe the relative hazard. Since backstops are normally used to terminate laser beams in the controlled area, and personnel downrange are equipped with adequate laser eye protection, scintillation is not usually important. Scintillation effects are most prominent

when the entire path is close to the surface of the earth.

C3. Calculating NOHD.

Table C1 provides conversion factors between the NOHD in a vacuum [NOHD(v)] and the NOHD in air (NOHD) assuming an atmospheric extinction coefficient of $5 \times 10^{-7} \text{ cm}^{-1}$ (0.05 km^{-1}). Even clear atmospheric conditions would generally provide attenuation of this magnitude. The NOHD(v) may be easily calculated in kilometers from the formulae in Appendix B, by assuming no attenuation. The attenuated NOHD in air (also in kilometers) may then be determined from Table C1. The NOHD for optically aided viewing can be estimated by multiplying the unaided NOHD(v) by the magnifying power of the optics. The NOHD(v) may then be converted to NOHD in air from Table C1.

C4. NOHD for Upward Directed Beams.

When the laser beam is directed up, less atmospheric absorption will occur due to thinning of the atmosphere. Therefore, attenuation values used for nearly horizontal laser beams are not appropriate. For lasers aimed 30° or more above the horizon, the transmission of the entire thickness of atmosphere will typically be about 60% to 80% for a day with good visibility and no cloud cover. A similar effect will occur for horizontal beams at high altitudes.

C5. References.

Deitz, P.H., Probability analysis of ocular damage due to laser radiation through the atmosphere. *Applied Optics*, 8(2), 371-375 (1969).

R.J. Hill, J.H. Churnside, and D.H. Sliney, Measured Statistics of Laser Beam Scintillation in Refractive turbulence Relevant to Eye Safety, *Health Physics*, 53 (6), 639-647, (1987).

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Table C1. Atmospherically Corrected Values of NOHD. Values are in kilometers. The NOHD in air for 60 km visibility ($\mu = 5 \times 10^{-7} \text{ cm}^{-1}$) can be determined when the NOHD in vacuum, is known.

NOHD(v)	NOHD	NOHD(v)	NOHD	NOHD(v)	NOHD	NOHD(v)	NOHD	NOHD(v)	NOHD
0.10	0.10	5.70	5.03	23.00	15.60	79.00	33.90	450.00	72.80
0.20	0.20	5.80	5.11	24.00	16.10	80.00	34.10	460.00	73.40
0.30	0.30	5.90	5.18	25.00	16.50	81.00	34.30	470.00	74.00
0.40	0.40	6.00	5.26	26.00	17.00	82.00	34.60	480.00	74.50
0.50	0.49	6.10	5.34	27.00	17.50	83.00	34.80	490.00	75.00
0.60	0.59	6.20	5.41	28.00	17.90	84.00	35.00	500.00	75.60
0.70	0.69	6.30	5.49	29.00	18.30	85.00	35.20	510.00	76.10
0.80	0.78	6.40	5.57	30.00	18.80	86.00	35.40	520.00	76.60
0.90	0.88	6.50	5.64	31.00	19.20	87.00	35.70	530.00	77.10
1.00	0.98	6.60	5.72	32.00	19.60	88.00	35.90	540.00	77.60
1.10	1.07	6.70	5.80	33.00	20.00	89.00	36.10	550.00	78.10
1.20	1.17	6.80	5.87	34.00	20.40	90.00	36.30	560.00	78.60
1.30	1.26	6.90	5.95	35.00	20.80	91.00	36.50	570.00	79.00
1.40	1.35	7.00	6.02	36.00	21.20	92.00	36.70	580.00	79.50
1.50	1.45	7.10	6.10	37.00	21.60	93.00	36.90	590.00	79.90
1.60	1.54	7.20	6.17	38.00	22.00	94.00	37.10	600.00	80.40
1.70	1.63	7.30	6.24	39.00	22.30	95.00	37.30	610.00	80.80
1.80	1.72	7.40	6.32	40.00	22.70	96.00	37.50	620.00	81.30
1.90	1.82	7.50	6.39	41.00	23.00	97.00	37.70	630.00	81.70
2.00	1.91	7.60	6.47	42.00	23.40	98.00	37.90	640.00	82.10
2.10	2.00	7.70	6.54	43.00	23.70	99.00	38.10	650.00	82.50
2.20	2.09	7.80	6.61	44.00	24.10	100.00	38.30	660.00	83.00
2.30	2.18	7.90	6.68	45.00	24.40	110.00	40.20	670.00	83.40
2.40	2.27	8.00	6.76	46.00	24.80	120.00	42.00	680.00	83.80
2.50	2.36	8.10	6.83	47.00	25.10	130.00	43.70	690.00	84.20
2.60	2.45	8.20	6.90	48.00	25.40	140.00	45.20	700.00	84.60
2.70	2.53	8.30	6.97	49.00	25.70	150.00	46.70	710.00	84.90
2.80	2.62	8.40	7.04	50.00	26.10	160.00	48.10	720.00	85.30
2.90	2.71	8.50	7.11	51.00	26.40	170.00	49.40	730.00	85.70
3.00	2.80	8.60	7.19	52.00	26.70	180.00	50.70	740.00	86.10
3.10	2.88	8.70	7.26	53.00	27.00	190.00	51.90	750.00	86.40
3.20	2.97	8.80	7.33	54.00	27.30	200.00	53.10	760.00	86.80
3.30	3.06	8.90	7.40	55.00	27.60	210.00	54.20	770.00	87.10
3.40	3.14	9.00	7.47	56.00	27.90	220.00	55.30	780.00	87.50
3.50	3.23	9.10	7.54	57.00	28.20	230.00	56.30	790.00	87.90
3.60	3.31	9.20	7.61	58.00	28.50	240.00	57.30	800.00	88.20
3.70	3.40	9.30	7.68	59.00	28.80	250.00	58.30	810.00	88.50
3.80	3.48	9.40	7.75	60.00	29.00	260.00	59.20	820.00	88.90
3.90	3.57	9.50	7.81	61.00	29.30	270.00	60.10	830.00	89.20
4.00	3.65	9.60	7.88	62.00	29.60	280.00	61.00	840.00	89.50
4.10	3.73	9.70	7.95	63.00	29.90	290.00	61.80	850.00	89.90
4.20	3.82	9.80	8.02	64.00	30.10	300.00	62.60	860.00	90.20
4.30	3.90	9.90	8.09	65.00	30.40	310.00	63.50	870.00	90.50
4.40	3.98	10.00	8.20	66.00	30.70	320.00	64.20	880.00	90.80
4.50	4.07	11.00	8.80	67.00	30.90	330.00	65.00	890.00	91.10
4.60	4.15	12.00	9.50	68.00	31.20	340.00	65.70	900.00	91.50
4.70	4.23	13.00	10.10	69.00	31.40	350.00	66.50	910.00	91.80
4.80	4.31	14.00	10.70	70.00	31.70	360.00	67.20	920.00	92.10
4.90	4.39	15.00	11.30	71.00	31.90	370.00	67.80	930.00	92.40
5.00	4.47	16.00	11.90	72.00	32.20	380.00	68.50	940.00	92.70
5.10	4.55	17.00	12.50	73.00	32.40	390.00	69.20	950.00	93.00
5.20	4.63	18.00	13.00	74.00	32.70	400.00	69.80	960.00	93.30
5.30	4.71	19.00	13.50	75.00	32.90	410.00	70.50	970.00	93.60
5.40	4.79	20.00	14.10	76.00	33.20	420.00	71.10	980.00	93.80
5.50	4.87	21.00	14.60	77.00	33.40	430.00	71.70	990.00	94.10
5.60	4.95	22.00	15.10	78.00	33.60	440.00	72.30	1000.00	94.40

Table C2. Reduction in NOHD for Reduced Visibility Conditions. The calculated NOHD in the first column is the NOHD in a vacuum. The NOHDs in the other columns are for reduced visibility conditions when the visibility is 60 km ($\mu = 0.05 \text{ km}^{-1}$), 20 km ($\mu = 0.15 \text{ km}^{-1}$), 10 km ($\mu = 0.35 \text{ km}^{-1}$), and 5 km ($\mu = 0.6 \text{ km}^{-1}$).

NOHD(v)	NOHD (60 km)	NOHD (20 km)	NOHD (10 km)	NOHD (5 km)
1	0.98	0.93	0.86	0.79
2	1.91	1.76	1.54	1.35
3	2.80	2.50	2.10	1.78
4	3.66	3.17	2.57	2.13
5	4.48	3.79	2.99	2.43
6	5.27	4.36	3.37	2.70
7	6.04	4.89	3.70	2.93
8	6.78	5.39	4.01	3.14
9	7.50	5.86	4.29	3.33
10	8.19	6.30	4.55	3.50
11	8.86	6.72	4.80	3.66
12	9.51	7.12	5.02	3.81
13	10.15	7.49	5.24	3.96
14	10.77	7.86	5.44	4.09
15	11.37	8.20	5.63	4.21
16	11.95	8.53	5.81	4.33
17	12.52	8.85	5.98	4.44
18	13.08	9.16	6.15	4.55
19	13.62	9.45	6.30	4.65
20	14.16	9.74	6.46	4.75
21	14.68	10.01	6.60	4.85
22	15.18	10.28	6.74	4.94
23	15.68	10.54	6.88	5.03
24	16.17	10.79	7.01	5.12
25	16.65	11.03	7.13	5.20
26	17.11	11.27	7.26	5.28
27	17.57	11.50	7.37	5.36
28	18.02	11.72	7.49	5.44
29	18.46	11.94	7.60	5.51
30	18.90	12.15	7.71	5.59
31	19.32	12.35	7.82	5.66
32	19.74	12.56	7.92	5.73
33	20.15	12.75	8.02	5.80
34	20.56	12.95	8.12	5.86
35	20.96	13.13	8.22	5.93
36	21.35	13.32	8.31	6.00
37	21.73	13.50	8.40	6.06
38	22.11	13.67	8.49	6.12
39	22.48	13.85	8.58	6.19
40	22.85	14.01	8.67	6.25

Table C3. Total Atmospheric Transmission Depending on Visibility. Values provided are for specific distances (1 km to 40 km) based on various visibility conditions when the visibility is 60 km ($\mu = 0.05 \text{ km}^{-1}$), 20 km ($\mu = 0.15 \text{ km}^{-1}$), 10 km ($\mu = 0.35 \text{ km}^{-1}$), and 5 km ($\mu = 0.6 \text{ km}^{-1}$).

Range (km)	Trans. (60 km)	Trans. (20 km)	Trans. (10 km)	Trans. (5 km)
1	9.5×10^{-1}	8.6×10^{-1}	7.0×10^{-1}	5.5×10^{-1}
2	9.0×10^{-1}	7.4×10^{-1}	5.0×10^{-1}	3.0×10^{-1}
3	8.6×10^{-1}	6.4×10^{-1}	3.5×10^{-1}	1.7×10^{-1}
4	8.2×10^{-1}	5.5×10^{-1}	2.5×10^{-1}	9.1×10^{-2}
5	7.8×10^{-1}	4.7×10^{-1}	1.7×10^{-1}	5.0×10^{-2}
6	7.4×10^{-1}	4.1×10^{-1}	1.2×10^{-1}	2.7×10^{-2}
7	7.0×10^{-1}	3.5×10^{-1}	8.6×10^{-2}	1.5×10^{-2}
8	6.7×10^{-1}	3.0×10^{-1}	6.1×10^{-2}	8.2×10^{-3}
9	6.4×10^{-1}	2.6×10^{-1}	4.3×10^{-2}	4.5×10^{-3}
10	6.1×10^{-1}	2.2×10^{-1}	3.0×10^{-2}	2.5×10^{-3}
11	5.8×10^{-1}	1.9×10^{-1}	2.1×10^{-2}	1.4×10^{-3}
12	5.5×10^{-1}	1.7×10^{-1}	1.5×10^{-2}	7.5×10^{-4}
13	5.2×10^{-1}	1.4×10^{-1}	1.1×10^{-2}	4.1×10^{-4}
14	5.0×10^{-1}	1.2×10^{-1}	7.4×10^{-3}	2.2×10^{-4}
15	4.7×10^{-1}	1.1×10^{-1}	5.2×10^{-3}	1.2×10^{-4}
16	4.5×10^{-1}	9.1×10^{-2}	3.7×10^{-3}	6.8×10^{-5}
17	4.3×10^{-1}	7.8×10^{-2}	2.6×10^{-3}	3.7×10^{-5}
18	4.1×10^{-1}	6.7×10^{-2}	1.8×10^{-3}	2.0×10^{-5}
19	3.9×10^{-1}	5.8×10^{-2}	1.3×10^{-3}	1.1×10^{-5}
20	3.7×10^{-1}	5.0×10^{-2}	9.1×10^{-4}	6.1×10^{-6}
21	3.5×10^{-1}	4.3×10^{-2}	6.4×10^{-4}	3.4×10^{-6}
22	3.3×10^{-1}	3.7×10^{-2}	4.5×10^{-4}	1.9×10^{-6}
23	3.2×10^{-1}	3.2×10^{-2}	3.2×10^{-4}	1.0×10^{-6}
24	3.0×10^{-1}	2.7×10^{-2}	2.2×10^{-4}	5.6×10^{-7}
25	2.9×10^{-1}	2.4×10^{-2}	1.6×10^{-4}	3.1×10^{-7}
26	2.7×10^{-1}	2.0×10^{-2}	1.1×10^{-4}	1.7×10^{-7}
27	2.6×10^{-1}	1.7×10^{-2}	7.9×10^{-5}	9.2×10^{-8}
28	2.5×10^{-1}	1.5×10^{-2}	5.5×10^{-5}	5.1×10^{-8}
29	2.3×10^{-1}	1.3×10^{-2}	3.9×10^{-5}	2.8×10^{-8}
30	2.2×10^{-1}	1.1×10^{-2}	2.8×10^{-5}	1.5×10^{-8}
31	2.1×10^{-1}	9.6×10^{-3}	1.9×10^{-5}	8.4×10^{-9}
32	2.0×10^{-1}	8.2×10^{-3}	1.4×10^{-5}	4.6×10^{-9}
33	1.9×10^{-1}	7.1×10^{-3}	9.6×10^{-6}	2.5×10^{-9}
34	1.8×10^{-1}	6.1×10^{-3}	6.8×10^{-6}	1.4×10^{-9}
35	1.7×10^{-1}	5.2×10^{-3}	4.8×10^{-6}	7.6×10^{-10}
36	1.7×10^{-1}	4.5×10^{-3}	3.4×10^{-6}	4.2×10^{-10}
37	1.6×10^{-1}	3.9×10^{-3}	2.4×10^{-6}	2.3×10^{-10}
38	1.5×10^{-1}	3.3×10^{-3}	1.7×10^{-6}	1.3×10^{-10}
39	1.4×10^{-1}	2.9×10^{-3}	1.2×10^{-6}	6.9×10^{-11}
40	1.4×10^{-1}	2.5×10^{-3}	8.3×10^{-7}	3.8×10^{-11}

Appendix D

Measurement Techniques for Outdoor Laser Applications

D1. General.

A comparison of divergence measurement techniques for outdoor laser applications was conducted in Las Vegas, Nevada in March of 1996. The following methods were found to be useful for field, laser beam divergence measurements. Much of the following material was extracted from Reference 1. The information in this appendix is also published as Reference 2. Viable methods other than those discussed here are also available and acceptable. No one method will always be appropriate in all situations. The correct method depends on the beam parameters, and the situational particulars of the laser tested, such as the space and equipment available. However, the two-point aperture method provides a simple, quick, and accurate technique for making most beam divergence measurements. It is desirable to produce measurements with less than 20% error in irradiance or radiant exposure, regardless of method used. It is understood that even this level of accuracy cannot always be attained, especially when considering atmospheric attenuation and scattering. In order to attain less than 20% error for beam irradiance or radiant exposure, the error in beam divergence should be less than 10%.

D2. Measurement Parameters.

D2.1 Measurement Aperture. The measurement aperture for unaided ocular viewing of lasers in the retinal hazard region, as defined in ANSI Z136.1, is 7 mm, which corresponds to a dark-adapted pupil. It is often useful to determine the retinal hazard from lasers operating in the retinal hazard region with a 7 mm aperture. A 5 cm aperture (the limiting aperture of 7 mm multiplied by a 7 power optical device) represents the potential hazards from viewing with standard magnifying optics, such as telescopes or binoculars. Measurement apertures of 1 mm and 3.5 mm are typically used to evaluate skin and corneal hazards. Table 3 of this standard lists the measurement apertures as they are defined in ANSI Z136.1-2000.

D2.2 Beam Profile. It is important to know the beam profile or power distribution of the laser that is being evaluated. Laser beams are typically modeled as having either a Gaussian (bell shaped) or uniform (top hat shaped) beam profile. In reality, there are no perfectly Gaussian or uniform beam profiles. Lasers are typically modeled to the profile to which they are

most similar. Models allow the use of ideal energy profiles, which ensure precise calculations and protection distances.

D2.2.1 Laser Beam Dimensions. For lasers operating in the retinal hazard region (between 0.4 μm and 1.4 μm), determination of beam dimensions less than 7 mm are generally not necessary to determine small source hazards. Beam dimensions may be necessary to determine the hazards from diffuse reflections. Beam dimensions either can be measured directly or can be calculated.

For laser safety calculations, the beam diameter of a circular laser at 1/e of the peak irradiance points is typically used. An aperture of this diameter will transmit about 63.2% of a laser beam with a Gaussian profile and 100% of a laser beam with a uniform profile. If the beam is rectangular or elliptical, the beam dimensions should be determined in each axis.

As a Gaussian laser beam propagates through space, it maintains a Gaussian profile. The beam diameter, D_L , is a function of range, r , from the exit port (or beam waist) and can be calculated as:

$$D_L = \sqrt{a^2 + r^2 \phi^2} \quad D1$$

where a is the beam diameter at the exit port and ϕ is the beam divergence (at 1/e of the peak irradiance points).

D2.2.2 Laser Beam Divergence. The laser beam divergence is a measure of the rate at which the laser beam diameter increases as a function of the range from the laser source. The divergence used in laser safety calculations is defined as the full angle of the beam spread measured between those points where the irradiance is equal to 1/e of the maximum value as shown in Figure D1.

D3. Measurement Techniques for Determining Laser Beam Divergence.

D3.1 Two-Point Aperture Method. The equations provided in this standard for this method require that the beam shape be circular, unless otherwise specified. Measurements to determine the divergence of a laser using the two-point aperture method require an optical detector, apertures of variable sizes, and a tape measure. The total power and the power passing through an aperture smaller than the beam diameter

at two locations downrange from the laser (as shown in Figure D2) are measured. When the exit beam diameter is very small, a single diameter measurement may be used, and the initial diameter may be assumed to be zero. When the initial diameter is larger than the limiting aperture, both aperture measurements should be performed well beyond any existing beam waist.

The relationship between Φ_d , the power transmitted through a circular aperture with a diameter, d , to Φ_0 , the total laser power is:

$$\Phi_d = \Phi_0 \left[1 - e^{-\frac{d^2}{D_L^2}} \right] \quad D2$$

This equation neglects atmospheric losses and may be solved for D_L as shown below:

$$D_L = \sqrt{\frac{-d^2}{\ln\left(1 - \frac{\Phi_d}{\Phi_0}\right)}} \quad D3$$

Similarly, if assuming a uniform beam profile, D_L can be calculated by:

$$D_L = d \cdot \sqrt{\frac{\Phi_0}{\Phi_d}} \quad D4$$

The total power and the power through an aperture at two points from a laser can be used to determine beam divergence. Either equation D3 or D4 can be used to determine the 1/e-beam diameters at each point down range, depending on the model used. The divergence is:

$$\phi = \frac{D_{L2} - D_{L1}}{r_{2-1}}, \quad D5$$

where D_{L1} is the beam diameter at the first point, D_{L2} is the beam diameter at the second point, and r_{2-1} is the distance between the two points. For rectangular or elliptical beams, Equation D5 may be used to calculate the beam divergence in each dimension when the respective beam dimensions at the two locations are substituted for D_{L1} and D_{L2} .

D3.2 Long Focal Length Lens and Aperture Method. The following equations for this method require that the beam shape be circular, unless otherwise specified. The divergence measurement using this method requires a long focal length lens, apertures of various sizes, an optical detector, a tape measure, and some means of aligning the lens, the

aperture, and the detector, e.g., optical table or tripods. The lens must be large enough to collect the entire laser beam and must have a known focal length, f . The setup for taking the measurement required is shown in Figure D3, where f is the geometric focal length of the lens, at the laser wavelength.

Although the actual focal point may not correspond exactly with the geometric focal length, the aperture must be placed at the geometric focal point. Care must be taken to ensure proper alignment for an accurate measurement. To accomplish this precision, often the aperture is placed in a fixture that uses a micrometer to fine-tune the position of the aperture in the focal plane of the lens to maximize power to the detector. The detector should be placed far enough from the actual focal point of the laser energy to avoid damaging the detector surface. Some laser beams are also powerful enough to damage or enlarge the aperture.

The beam diameter is the size of an aperture that passes 63% of the total power of a Gaussian profiled laser beam. For a uniform beam, the beam diameter is the size of an aperture that passes just less than 100% of the total power. The beam diameter of the beam at the focal length of the lens is D_{fp} . The value of D_{fp} can be calculated for a Gaussian laser from the percentage of the total power transmitted through the aperture as follows

$$D_{fp} = \sqrt{\frac{-d^2}{\ln\left(1 - \frac{\Phi_d}{\Phi_0}\right)}}, \quad D6$$

where d is the aperture diameter, Φ_d is the power transmitted through the aperture, and Φ_0 is the total power. Similarly, if assuming a uniform beam profile, D_{fp} can be calculated by using Equation D4 and substituting D_{fp} for D_L .

The dimensions of the laser beam at the geometric focal point of the lens for a rectangular beam cannot be determined by measurements through an aperture. However, they may be determined by the use of a beam profiler camera, sensitive to the laser wavelength, placed in the focal plane. The divergence(s) of either a circular or non-circular laser beam can then be calculated by:

$$\phi = \frac{D_{fp}}{f}. \quad D7$$

D3.3 Knife-Edge Technique. Measurements to determine the divergence of a laser using this method

require a focusing lens, a knife edge with micrometer adjustment, an optical detector, and some means of aligning the lens, the knife edge, and the detector (e.g., optical table or tripods). The setup is very similar to the long focal length lens with small aperture method and is shown in Figure D4, where f is the focal length of the lens. The lens must be large enough to collect the entire beam and the focal length, f , of the lens must be known at the laser wavelength to calculate the beam divergence with this technique. The knife-edge is placed in a fixture that uses a micrometer to move the edge through the beam at the focal plane of the lens. If the beam is not circular, then this technique should be done in both axis of the beam profile to determine each beam dimension.

Assuming a Gaussian beam profile at the focal length of the lens, the knife-edge is positioned at the location where 86.5% of the energy is transmitted to the detector and at the location where 13.5% of the energy is transmitted to the detector. The positions of these two measured locations is recorded with a micrometer. The difference in these two positions, $X_{86.5}$ and $X_{13.5}$, provides the radius, ω , of the Gaussian beam at $1/e^2$ of peak irradiance points:

$$\omega = X_{86.5} - X_{13.5} \quad D8$$

The $1/e$ focused beam diameter of a Gaussian beam, D_{fp} , is then,

$$D_{fp} = \sqrt{2}\omega \quad D9$$

For a uniform beam profile, the difference in positions from where the laser beam energy begins to decline and where the beam energy is barely detectable, is the beam diameter. Diameters measured at either $1/e$ or $1/e^2$ points are equal when assuming a uniform profile. The divergence of the laser can then be calculated by using Equation D7.

D3.4 Beam Profiler Method. Commercial laser beam profilers are available to measure the parameters of a laser beam. Measurements to determine the divergence of a laser using this method require a focusing lens, tape measure, optical detector, beam attenuation filters, beam profiling system, and some means for alignment (e.g., optical table or tripods). The setup is very similar to the long focal length lens with small aperture method. Beam attenuator filters are usually needed so as not to saturate or destroy the beam profiler camera. The lens must be of sufficient size to collect the entire laser beam. A precise measurement is obtained when the focused spot size is at least 50% of the active area of the camera. If the focused spot size is too small, this

measurement can have significant error. Due to the lack of portability, profilers are normally best suited for a laboratory environment.

D4. Comparison of Techniques.

The advantages and disadvantages of each technique are given in Table D1.

D5. References.

1. Zimmerman, Sheldon; and Aldrich, Robert; "Comparison of Divergence Measurement Techniques for Laser Light Show Application," Proceedings of the Third International Laser Safety Conference, Laser Institute of America, 1997.
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5. Thomas, Robert J.; Maier, Dennis A.; Barsalou, Norman; McLin, Leon; Lambert, LeRoy; and Keppler, Kenneth. "Laser Light Show Measurement Techniques," *SAFE Jour* 27 (2) 115-126 (1997).

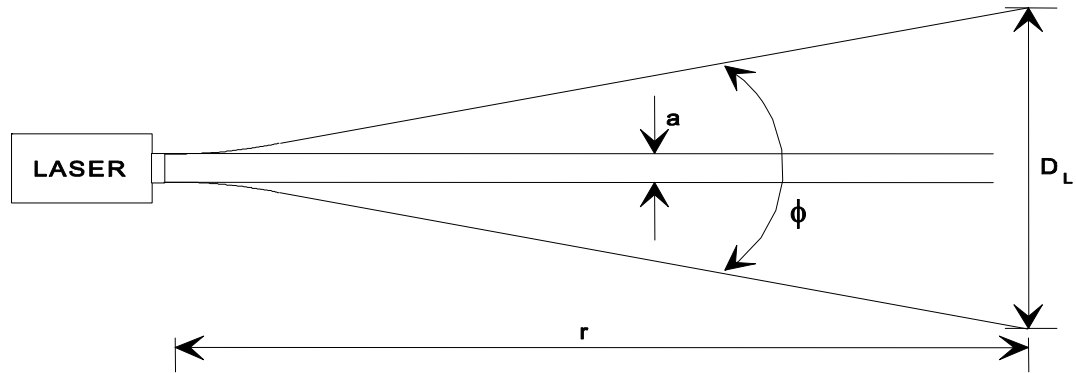


Figure D1. Laser Beam Geometry.

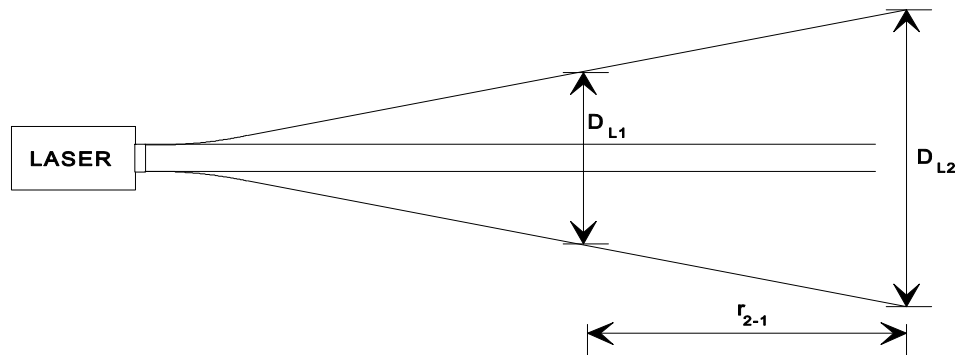


Figure D2. Two Point Method.

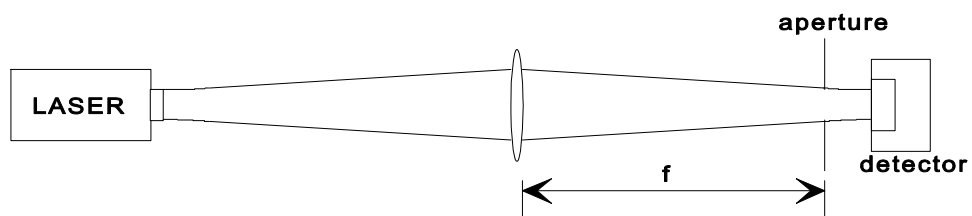


Figure D3. Long Focal Length Lens and Small Aperture Method Setup.

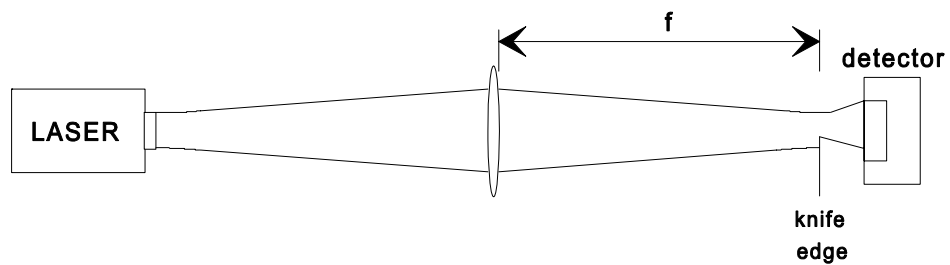


Figure D4. Knife-Edge Method Setup.

Table D1. Laser Beam Divergence Measurement Techniques.

Technique	Pros	Cons
Knife Edge with Focusing Lens	Very accurate for laboratory measurements Requires little distance (usually 2 to 5 meters) Can be used with non-circular beams	Requires an Optical Table with several components Requires focusing the beam (can cause dangerous power densities) Takes a long time (a few hours) to set up and take measurements Not practical for many outdoor environments Requires advanced understanding of optics Requires expensive focusing lens and folding mirrors Requires an extremely stable optical platform
Fixed Aperture with Focusing Lens	Very accurate for laboratory measurements Requires little distance (usually 2 to 5 meters) Less complex than Knife Edge Technique	Requires focusing the beam (can cause dangerous power densities) Not practical for some outdoor environments Requires expensive focusing lens Requires advanced understanding of optics Requires a very stable optical platform Requires about an hour of setup and measurement time Cannot be used for non-circular beams without using different equations
Two-Point Aperture	Easy to perform measurements and calculations requiring little training Fast & convenient technique requiring only a few minutes for setup and laser-on time Fewer equipment requirements – fits in one case Portable setup No need for stable platform means that one is able to work in a variety of environments (e.g., on a ladder) Safer technique due to fewer reflective surfaces No need to focus the beam Quickly and easily repeatable for double-check	Can require relatively long ranges to determine beam divergence for lasers with very large exit beam sizes or very small beam divergences (e.g., a 2 cm beam with a divergence of 0.5 mrad would require a range of 18 meters, assuming at least a 10% change in beam size between the measurement points). Range can be a problem, but with the portable property of this technique, this is rarely so. (By comparison, a 5 mm beam with a divergence of 1 mrad can be measured in 2.3 meters, assuming at least a 10% change in beam size between the measurement points) Cannot be used for non-circular beams without using different equations
Beam Profiler	Very accurate technique Provides extra beam information Requires less knowledge of advanced optics concepts Does not require a circular beam	Difficult to perform without much training Not very portable Expensive beam profiler required Profiler camera is easily damaged Requires focusing the beam (can cause dangerous power densities)

Appendix E

Outdoor Laser Safety Analysis Methodology

[NOTE: This guideline is directed at safety/risk analysis for in-flight aircraft only. This guideline does not address the safety of users of laser systems or members of the public that are not “in-flight”.]

E1. Operational Volume and Hazard Distances.

In order to perform an evaluation of the laser systems, the actual spatial volume of operation and power levels of the laser must be determined.

E1.1 Elevation and Azimuth. Determine ranges of elevation and azimuth that will be used for the proposed system operations. [Many laser systems are fixed, others operate over a range of directions and elevations. The actual elevations and azimuth directions of planned operation need to be defined in order to evaluate air space that will be potentially affected, e.g., the spatial volume of operation.]

E1.2 Hazard Distances. Determine hazard distances of the proposed laser. Each hazard classification must be addressed for the laser operations. When the NOHD exceeds one of the other distances, it takes precedence. If a laser will operate at varying power levels, the worst case should be addressed. The following distances need to be calculated:

- (1) Nominal Ocular Hazard Distance
- (2) Laser-Free Exposure Distance
- (3) Critical Exposure Distance
- (4) Sensitive Exposure Distance

Lasers operating outside of the visible spectrum do not require the distances (2)-(4).

E1.3 Operational Volume. Illustrate the site, operational volume and hazard distances on the Visual Flight Rules (VFR) map. VFR maps are maps typically used by pilots. They provide airport locations and other important flight data. By overlaying the projected area of the operational volume and hazard distances on a VFR map, a “picture” of the potentially affected volume can be obtained.

E2. Local Airports and Flight Hazard Zones.

In conjunction with paragraph E1 above, the flight hazard zones (laser-free, critical and sensitive) are

identified around the airports. Using the FAA VFR map from E1, identify all airports near the proposed laser site. Identify the laser-free, critical, and sensitive zones around each of the identified airports (see Figures 4-6). Illustrate the flight hazard zones on the VFR map for each area airport.

Airport zones beyond the greatest distance identified in E1 need not be considered. Airports with zones that do not overlap the respective hazard distances and operating volumes identified in paragraph E1 do not need to be considered further.

NOTE: The NOHD is not zone specific. If the laser will produce an eye hazard within navigable airspace, the hazard to air traffic must be evaluated.

E3. Air Traffic Patterns and Densities.

If an airport flight hazard zone is impacted by the laser operation or an NOHD will penetrate navigable air space, air traffic patterns and densities should be determined to evaluate the magnitude of potential impact.

Request assistance of the FAA for:

(1) Historical aircraft patterns, for a one-year period, near the proposed laser site. (Consideration should be given to density changes based on time of day and seasonal air traffic activities. Air traffic densities would also need to be considered outside of airport related activities for laser operations producing an NOHD.)

(2) Aircraft landings and take-offs for the airports identified in E2. This information can be coordinated with standard approach and departure routes to estimate flight path densities.

E4. Relative Risk of Airspace.

The objective of this step is to identify defined volumes of airspace that have higher or lower risk levels as a result of flight hazard zones, patterns and densities. This information can be useful in determining control techniques and methodologies.

Evaluate the airport flight hazard zones identified in E2 and the air traffic patterns and densities identified in E3.

Identify the relative risk levels of the airspace based on the evaluation in E4. This can be illustrated on a basic graph, Figure E1.

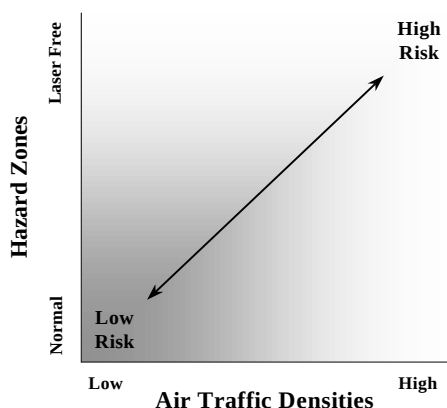


Figure E1. Relative Risk Based on Air Traffic Densities and Flight Hazard Zones.

E5. Aircraft Considerations.

Since balloons, blimps, and rotary aircraft often travel very slowly, exposure duration of personnel may be longer than would be experienced with faster aircraft. Additionally, personnel in blimps, balloons, or ultralight aircraft, may not be protected by windscreens; they could be exposed by far-infrared lasers that would normally be blocked by windscreens. Control measures should be capable of detecting personnel in these types of aircraft as well as more conventional types.

E6. Defining Laser Operations.

It is necessary to further define the actual lasing activity:

- A. Determine duration (minutes, hours, etc.) of the proposed laser event.
- B. Define when the events will occur.
 - (1) Time of day or night
 - (2) Days per week and which days of the week
 - (3) Time of the year
 - (4) Required or allowable weather conditions for a laser event (e.g. clear weather, cloudy weather, etc.)
- C. Determine how the transmitted laser beam will propagate through the atmosphere during the event (e.g. sweep an arc, vertical stationary beam, etc.).

E7. Relative Risk of the Laser Operations.

The objective of this step is to balance the hazards presented by the laser (hazard distances) with the time, duration and conditions of the operations. (e.g.,

a laser with short hazard distances fired in a fixed direction for only 2 minutes a month would be a very low hazard, whereas a laser with long hazard distances fired in a variety of directions and continuously over a month would be a high hazard.)

Evaluate the hazard distances determined in E1 and the laser operations defined in E5.

Identify the relative risk of the laser operations.

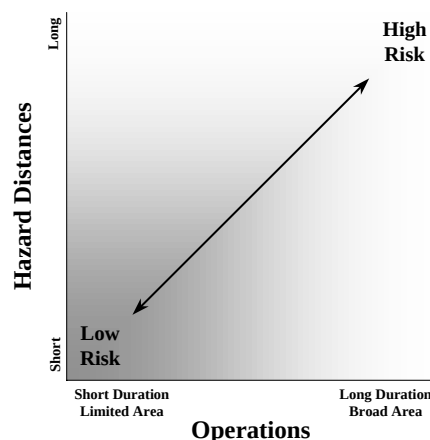


Figure E2. Relative Risk Based on Operations and Hazard Distances.

E8. Relative Risk of Laser Operations versus Air Space.

Evaluate the combination of E5 and E6 to provide a qualitative risk level for the proposed laser operations at the proposed site as illustrated in Figure E2. When combined with the hazard distance relative to the at-risk air space/flight hazard zones and the operational requirements and limitations of the laser operations, this qualitative risk level assists in identifying the types and levels of protection required. Figure E3 is a combination of Figures E1 and E2.

E9. Preventive Methods.

See Appendix F for specific aircraft detection methods.

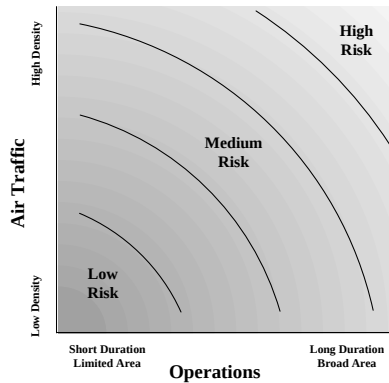


Figure E3. Relative Risk Based on a Combination of Operations and Air Traffic.

E9.1 Preventive Techniques and Associated Ranges. A variety of factors influence the actual effective range of preventive techniques. Figure E4 illustrates the types of control measures that could be deployed depending on the distances necessary to protect from laser exposure.

E9.2 Aircraft Illumination Avoidance Method. The choice of preventive technique(s) should be based on the level of hazard presented by the laser operations. The above analysis provides information to be used in the determination.

1. Identify, in detail, all methods, procedures, systems, hardware, software, etc. that will be used to avoid the illumination of aircraft with the transmitted laser beam.
2. Document and maintain on file all analyses and approvals.
3. Re-evaluate the analysis and preventive techniques whenever the system or operational parameters are modified or approximately every 5 years if no changes are made.

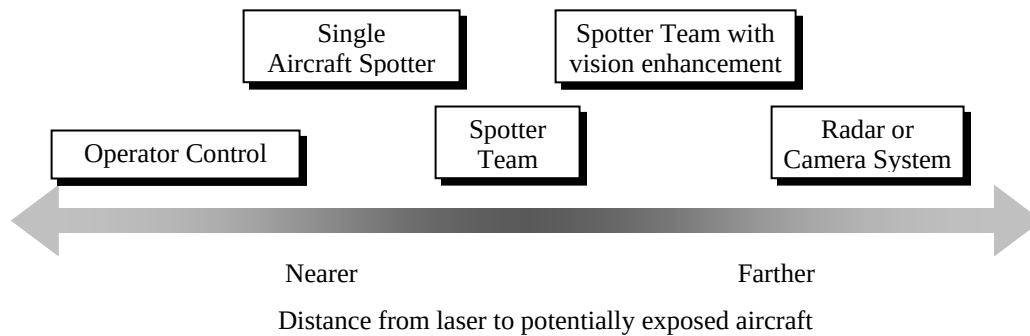


Figure E4. Reasonable Control Techniques. Control techniques employed depend on clutter (city lights), density of air traffic, proximity of local airports, number of lasers employed, and protection distances for the lasers used.

Appendix F

Aircraft Detection Systems

The following systems or technologies are effective only if the laser system is appropriately installed and operated in accordance with federal, state and local regulations, and industry standards. Issues of concern include stability of the laser and platform, physical access to the laser, pointing accuracy of the laser beam, protective housings, and unwanted wavelengths of laser energy. These issues need to be addressed prior to placing the system into operation. For additional information on outdoor control measures see SAE Aerospace Recommended Practice ARP 5535, and for additional requirements for safety observers, see ARP 5572.

F1. Safety Observer.

The safety observer detects aircraft through sight and sound and can initiate the termination of the laser beam. The safety observer is one of the more proven methods of ensuring that aircraft are not illuminated in-flight by a laser beam. Distance, atmospheric, and environmental parameters may reduce the effectiveness of safety observers. Additionally, the wavelength (visible versus non-visible) of the laser beam may further reduce the ability of the safety observer to identify the affected airspace. Safety observers may be used in conjunction with other control measures for high-powered laser systems.

Safety observers have been demonstrated to be reliable in detecting aircraft at night within short distances (i.e., within about 3 miles) in populated areas. They may be reliable in detecting aircraft farther in semi-populated areas and at much greater distances in remote locations, where city lights are not encountered. The Laser Safety Officer (LSO) should not rely solely on safety observers if aircraft can be exposed to hazardous levels of laser energy beyond the observer's effective visual range.

Safety observers have limited visible range, require training, need frequent breaks, and may be affected by certain environmental conditions. However, safety observers may have a wider field of view when scanning the airspace, may be readily available, and may be more economical for short-term laser operations.

F1.1 Binoculars. Binoculars can be used to magnify the image and aid in early identification of aircraft. However, use of such devices can drastically reduce the observer's field of view and the area being scanned.

F1.2 Light Amplification devices. Safety observers have used night vision goggles (NVGs) to detect aircraft in nighttime conditions. However, NVGs exposed to bright lights can cause blooming from the light and glare or flashblindness to the observer. Also, NVGs can reduce the observer's field of view, reducing the airspace that can be scanned. Observers should be instructed in the proper use of NVGs prior to their use. In particular, proper focusing of the NVG is critical. Most NVGs project an "image" of the field of view on a screen and therefore do not pass laser energy through the device to the eye, however there remains a hazard from beams (incident or reflected) obliquely entering the eye. Additionally it should be noted that some newer NVGs superimpose the amplified night scene onto a direct optical path view. These systems (unless fitted with appropriate filters) DO NOT afford protection to the user from laser energy.

F1.3 Visible Alignment Beams. A visible alignment beam can be used to assist the safety observer in identifying the direction of an invisible laser beam; however, a visible beam may attract unwanted attention.

F2. Radar.

Radar sends out a radio frequency (RF) signal and displays the signal return reflected from an object. The distance to the object is calculated from the amount of time the signal takes to travel to-and-from the object. Radar is restricted to line-of-sight. Aircraft maneuvers, such as steep turns, rapid climbs or descents, can degrade the radar reflection. Radar is subject to limitations including atmospheric conditions, missed targets, false returns, ground clutter, RF interference, etc.

F2.1 Boresight (Co-aligned) Radar. Boresight radar systems use radar technology to monitor the specific region of airspace that is in the direction of propagation of the laser beam. If the laser beam can be re-directed, the boresight radar system changes its direction along with the laser.

Boresight radar systems are typically used by scientific, research, or military laser operations that transmit laser energy through the navigable airspace. Satellite laser ranging systems, LIDAR systems and guide star optical telescopes have used this system either by itself, or in combination with other aircraft

detection systems, such as safety observers or cameras.

Boresight radar systems are commercially available. As with any control measure, the capability of a boresight system should be evaluated based on the specific proposed operation. Since the radar is pointing along the transmitted laser beam and constantly monitoring the airspace, it is extremely reliable for detecting aircraft. In addition, the time from detection of the aircraft to the development of the aircraft detect signal is usually in milliseconds. These laser abatement systems may be situated in remote locations or placed near densely populated areas.

The boresight radar system is effective even when other control systems are hampered by poor visibility. The boresight radar has a wide range of coverage (from a few hundred feet to tens of miles). Its very quick response time lends itself well to areas of high-volume air traffic.

The boresight radar system would not be used when there is a potential that transmitted RF energy may interfere with other established operations, such as communication transmissions, deep space monitoring systems, and radio telescopes. Also, the boresight radar system should not be used if ground based objects interfere with the capability of the system. Therefore, not all boresight radar systems are well suited for laser systems that transmit laser energy close to the ground. Local and federal laws and regulations may limit the use of RF energy generating devices, such as radar systems.

F2.2 Scanning Radar (Sweeping & Panning).

Scanning radars encompass a vast array of equipment ranging from inexpensive, portable, analog radar systems, such as those used on small boats, to permanent installations of a multi-million dollar digital radar systems found at airports.

A scanning radar system rotates or oscillates about an axis. The time to perform a complete rotation varies among different radar systems. This rotation time prevents real-time or near real-time display of aircraft location and movement. The direction and speed of the aircraft and the radar rotation time must be taken into account to predict the position of the aircraft.

The distance and coverage angles of scanning radar systems differ widely. Sweeping radar systems scan 360° about a vertical axis and have a conical volume of airspace directly above the radar antenna that is excluded from radar coverage – sometimes called a blind spot. Panning radar systems scan only a portion of the airspace. Although possibly enhancing

situational awareness, scanning radar may be of limited value to the laser operator.

F2.3 Phased Array Radar. Phased array radar systems utilize a specific geometrical arrangement of stationary antennas and software to emulate the abilities of sweeping and boresight radars. A phased array radar has no refresh delay or high elevation angle exclusion zones normally attributed to sweeping radars. Additionally, these radar systems are very expensive and have high maintenance costs. The phased array radar permits complete flexibility in its use. Search and tracking functions can be adjusted to optimum use based on local conditions. The radar beam width, azimuth, and elevation can be adjusted to search certain areas more rapidly than others. Even the power transmitted through each element can be adjusted to optimize the beam for specific classes of object detection, discrimination and tracking. All of these functions are adaptively programmable and offer the capability to automate the management and control system for the radar.

With the capability to track multiple objects simultaneously, a phased array radar system can easily handle high-density air traffic situations. Because the power and phase of the radar pulses can be adjusted for each transmitting antenna element, customized radar beams can be created for specific detection and tracking requirements. This can be analogous to the boresight radar capability.

F2.4 Secondary Radar. Secondary radar is a term used by the FAA to describe a method of determining aircraft location that relies on a transponder in the aircraft to transmit location data after being interrogated by a remote transmitter beacon. Secondary radar normally has a range of up to 60 miles. Since secondary radar requires transponder information and because not all aircraft have transponders, secondary radar should not be used as the sole laser control measure in airspace that does not require all aircraft to use transponders.

F2.5 Traffic Collision Avoidance System (TCAS).

TCAS is a self-contained secondary radar system. It displays the location and altitude of transponder-equipped aircraft within its detection range. TCAS was originally designed for use in aircraft to provide a warning when a potential collision with another aircraft is predicted, but can provide information about local transponder-equipped aircraft that may not yet be within visible range of a laser safety observer. TCAS is most useful in adequate but marginal visibility conditions, such as light fog, smog, or city lights.

F2.6 Radar Airspace Monitoring System (RAMS). The Radar Airspace Monitoring System (RAMS) uses radar data provided by the FAA in support of laser operations. This data is sent over a dedicated phone line via secure modems. A computer monitor at the laser proponent's facility displays live information similar to an air traffic controller's radar screen. Aircraft appear as dots in their last detected position relative to the site. The display has a trail of past locations, thus providing the flight path history of the aircraft in relation to the laser activity. RAMS also provides a second view that displays a graphical representation of aircraft elevation within a radius of the laser facility. Combined, these views provides a three dimensional representation of aircraft in the immediate area in relation to laser activities. This system requires the user to manually input the laser beam pointing direction and does not currently interface directly with any laser abatement systems.

Systems that depend on FAA secondary radar data are best suited where aircraft are required to have operating transponders. RAMS is in use at Sandia National Laboratory and at the Air Force Research Laboratory's (AFRL) Starfire Optical Range. RAMS is especially valuable in the daytime or inclement weather when small or high-altitude aircraft are more difficult to see. RAMS data can serve as an adjunct to the laser safety observer. It is not intended to replace safety observers who are visually scanning the airspace to ensure the laser beam is safe to propagate.

F3. Solid-State Infrared Cameras.

A solid-state infrared camera system is optimized to detect specific infrared wavelengths. This type of camera system senses the infrared energy emitted by objects in the field of view of the camera, such as aircraft, buildings, and mountains. The camera then generates an area image that contains these objects. These cameras can effectively be used in both daytime or nighttime environments and can be boresighted with the laser beam. The system may be based on a combination of multiple cameras with different fields of view or sensitive to different spectral frequencies. The system creates a series of images that depict the motion of objects in the field of view, which can be discriminated by a computer with motion detection software.

A typical system is capable of monitoring aircraft at ranges from about 0.25 to 2 miles from the camera. The camera system is used to provide an aircraft detection signal. The signal may be used to notify the laser operator that an aircraft has been detected.

Additionally, the signal can be used to automatically activate a laser abatement system or other control measure.

The advantage of an automated camera system is that it provides a laser safety control measure for the detection of low flying aircraft and is not affected by the fatigue or distraction that is normally associated with safety observers. The automated camera system is dependent upon acquisition of the aircraft within the field of view of the camera lens. Poor visibility conditions (e.g., fog, clouds, dust, and smoke) can impair the range and motion detection performance of the camera system.

F4. References.

- SAE International, The Engineering Society for Advancing Mobility Land Sea Air and Space, Aerospace Standard, AS4970, *Human Factors Considerations for Outdoor Laser Operations in the Navigable Airspace*, 1999-1
- SAE International, ARP5535, "Observers for Laser Safety in the Navigable Airspace", 2003-07
- SAE International, ARP5572, "Control Measures for Laser Safety in the Navigable Airspace", 2004
- FAA, AC No. 70-1, "Advisory Circular: Outdoor Laser Operations", 2004
- International Civil Aviation Organization (ICAO), "Manual on Laser Emitters and Flight Safety," Doc 9815, AN/447, First Edition—2003

Appendix G

Training Requirements

G1. General.

Laser operators/workers should receive training commensurate with the specific lasers with which they will be associated and to the highest class lasers to which they may be exposed. This training may be in the form of a formal course or may be administered through specific standing operating procedures and literature supplied by the LSO.

G2. Laser Safety Specialists.

Formal education in algebra, geometry, and trigonometry is required. A bachelor's degree or higher in physics, engineering, or mathematics is preferred. Specialized training and experience is required concerning laser beam propagation, laser physics, electro-optics, radiometric measurement methods, consensus standards, federal and international laser safety standards, and biological effects of lasers on the skin and eyes. This training should include, but not be limited to the following:

- (1) fundamentals of lasers and optics
 - a. radiometric terms and units
 - b. laser fundamentals
 - c. optics principles
- (2) biological effects of laser radiation
 - a. exposure limits
 - b. injury levels
 - c. visual interference effects
- (3) laser hazard evaluation
 - a. hazard classification
 - b. environmental factors
 - c. nominal hazard zone
 - d. flight hazard zone
 - e. hazard calculations
- (4) laser safety standards
 - a. ANSI Z136.1
 - b. 21 CFR 1040.10 and 1040.11
 - c. 29 CFR 1910.147, 1910.132, 1915.152, 1926.95
 - d. state regulations

- e. FAA Order 7400.2
- (5) control measures
 - a. administrative
 - b. engineering
 - c. personal protective
- (6) laser safety program administration
 - a. LSO duties
 - b. SOPs
 - c. employee training
- (7) Laser safety measurements

G3. LSMO LSO.

The LSMO LSO should receive training including:

- (1) the hazards in the use of outdoor lasers
- (2) hazard evaluation procedures
- (3) control measures
- (4) applicable standards (FAA, Air Force Space Command, 21 CFR 1040.10 and 1040.11, ANSI Z136.1 and 29 CFR, etc.)
- (5) medical surveillance
- (6) laser safety consultant services
- (7) incident investigation and reporting
- (8) emergency procedures for prompt medical attention
- (9) safety
- (10) inventory control
- (11) record keeping required as a condition of FDA/CDRH exemptions

G4. Site LSO.

The site LSO should receive pertinent training specific to the restrictions required for using lasers at a particular installation. This training includes:

- (1) company laser safety policy
- (2) hazards and control measures associated with use of outdoor lasers
- (3) recommendations by laser safety consultants for safe use of lasers on a particular range

- (4) laser safety approval procedures
- (5) preparing instructions for laser users
- (6) ensuring that proper physical barriers are in place and warning signs are posted
- (7) incident investigation and reporting
- (8) emergency procedures for prompt medical attention and safety
- (9) keeping records of laser use and control measures

G5. Authorized Laser Operators.

Operators of Class 3B and Class 4 lasers should receive specialized training for the lasers that they will operate. This training should include: specific laser control measures, applicable SOPs, environments in which lasers may or may not be used, communication requirements, safety approval authorities, applicable government (FAA, FDA/CDRH, OSHA, DoD, etc.) local regulations, and certification of users. This training is in addition to the training outlined ANSI Z136.1.

G6. Personnel in the Target Area of a Laser.

For a specific test involving Class 3B and Class 4 lasers, personnel are sometimes required to be in the beam path near the point of impact on a suitable backstop. When the MPE is exceeded at this location, personnel within the NHZ should receive hands-on training on the specific procedures contained in the laser safety SOP. This training should include communications, proper donning and type of required laser eye protection, buildings in which they must take cover, hazards and control measures associated with lasers to which they may be potentially exposed.

G7. Safety Observers.

Laser Safety Observers should receive training on all of the following topics (where applicable):

(1) Optical Scanning Patterns. Scanning in regular patterns allows the observer to view a specified sector of space efficiently. It also discourages the manifestation of illusions, such as the “empty-field myopia” or “night myopia.” Detection of aircraft is increased with scanning of smaller areas of space.

(2) Proper Use of Ophthalmic Devices. Eyeglasses with darkly tinted lenses should not be used during night laser operations because they may reduce vision performance and result in missed detection of aircraft. Additionally, tints that alter

color perception, such as blue blockers, should not be used. Contact lenses that change the color of the iris are also discouraged during night laser operations as they can reduce both central and peripheral vision.

(3) Communication Requirements and Equipment. To ensure proper communication with air traffic service and other laser personnel, observers should be properly instructed on the use of radio, cell phone, telephone, or other communication equipment.

(4) Safe Operating Procedure Logbook. Such a logbook should be filled out appropriately each time the laser is operated. The location and maintenance of this book is the responsibility of the LSO.

(5) Use of Control Measures. The proper use of all laser beam control measures that are available and the protocols as to when such control measures are used should be reviewed.

(6) Training on Visual Illusions. Visual illusions are more common at night. In the darkness, a condition of “dark-field myopia” or “night myopia” occurs and the individual becomes more nearsighted. When looking into empty space or a featureless field of vision, “empty-field myopia” can occur.

(7) Fatigue Recognition. Individuals should be trained to recognize fatigue while scanning for aircraft. Common side effects of fatigue include distraction or cognitive disruption. It is recommended that observers be provided periodic rest breaks to ensure optimal performance. A 10-minute break for each 60-minute period of observation duty is usually adequate. In high traffic areas, breaks may need to be more frequent. At higher altitudes (i.e., > 5,000 feet above sea level), where altitude hypoxia can be a factor, fatigue may occur at shorter time intervals.

(8) Viewing Conditions. Prolonged exposure to bright lights can result in fatigue. Also, glare can result in visual acuity and contrast sensitivity decrements. In nighttime conditions, the visual illusions previously mentioned need to be considered.

(9) Effects of Environment. In an urban environment, artificial lights can affect the contrast between aircraft and the background. In a rural environment, lack of surface detail can result in illusions. Haze can scatter light affecting visibility and reducing detection range. Inclement conditions, such as rain, snow, mist and fog, can affect visual performance. Natural or man-made obstructions such as mountains, trees, or buildings can block the view of safety observers. A bright star-filled sky can mask aircraft position lights.

(10) Multiple Tasking. When an individual is tasked with multiple assignments, distraction and fatigue are increased. A laser safety observer should only be tasked with pertinent duties that affect safety, which include scanning for aircraft, communicating with air traffic services and/or laser personnel, and terminating laser beams, if illumination of aircraft is imminent.

(11) Judgment. Training should include how to anticipate aircraft flight characteristics and also the potential for hazardous illumination of the aircraft and pilot. Observers should always be alert for the unexpected movements of a particular aircraft or of the unexpected appearance of aircraft in a portion of the sky.

(12) Performance Requirements. Moderate, steady air traffic is less likely to induce fatigue. In an environment with very few or many aircraft, a safety observer is more likely to have fatigue, resulting in effects ranging from boredom to sensory overload. Reducing the field of view with multiple observers or reducing the duty time of the observer can minimize these side effects.

(13) Physiological Effects. Certain situations or conditions may have significant effects on human physiology, and as such may impact visual performance. On average, it takes about 30 minutes for an individual to fully adapt to the dark. When an individual has prolonged exposure to bright lights, the time for dark adaptation will be lengthened. Use of appropriate sunglasses in daylight hours can improve dark adaptation. Use of tobacco products can delay dark adaptation. As we age, adaptation to bright lights and to the dark can be affected. Use of certain drugs or alcohol can affect judgment and physiology. The use of micronutrients and antioxidants has been recommended to improve vision and resist the progression of eye diseases. For example, vitamin A can improve night vision capability.

(14) Visual Stimuli. Visual stimuli have unique characteristics, and some stimuli are easier to detect than others. For example, a moving or flickering light source is easier to detect than a steady light source. Aircraft navigation lights are aviation red (left wing) and green (right wing), indicating the direction of flight. Due to the eye's inherent peak sensitivity, green lights are easier to see than red lights. Off-axis viewing is a technique used to enhance aircraft acquisition at night. Looking directly at the target at night decreases the ability to detect that aircraft. The observer must look slightly away (off-axis) from the aircraft to see it.

(15) Local Air Traffic Patterns. When available, the LSO should provide information on local air traffic and facilities to safety observers prior to laser operation. This will assist the observers in scanning for aircraft near the area of laser beam propagation. Radio scanners tuned to air traffic frequencies may also assist in acquiring aircraft.

Appendix H

Visible and Invisible Laser Radiation — Problems in Laser Safety Terminology

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

Abstract

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

H1. Background.

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

between 360 and 400 nm and the upper limit between 760 and 830 nm.”

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

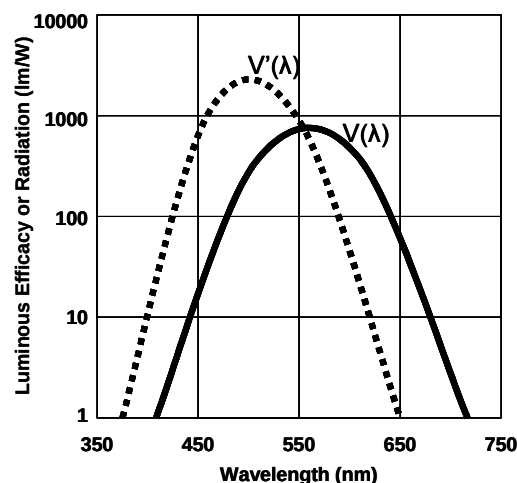


Figure H1. Photopic luminous sensitivity. The eye’s photopic (daylight) (spectral response) function [$V(\lambda)$] for the CIE standard observer. For comparison, the scotopic (night-vision) function [$V'(\lambda)$] is shown as a dashed line.

Note that the full width at half maximum spectral sensitivity points are at 510 and 610 nm, leading to a “spectral bandwidth” of only 100 nm by some

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

H2. Class 2 “visible” lasers.

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

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

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

H3. The “invisible laser.”

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

H4. Recommended practice.

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

would be used in leveling and alignment and for visible laser pointers. No change in the MPE values are anticipated in these spectral transition zones at this time. To some, the choice of 5% or 10% response points would be as arbitrary as the earlier choice of 400-700 nm band. We should really review the evidence for the aversion response.

The aversion response is the rapid pupillary closure, eye movement, and lid closure (blink) that takes place when one is suddenly presented with an intensely bright stimulus. The aversion response is thought to limit exposure of a specific retinal area (for small sources) to 0.25 seconds or less by eye or head movements and by partial (squint or pupillary response) or total occlusion (blink) of the pupil. The assignment of a duration of 0.25 s to this “aversion response” in laser safety standards has frequently been misunderstood to be based upon a sharply defined physiological point, and this duration has even been referred to as the “blink reflex,” which, when it occurs, is really of the order of 0.16 s. The choice of 0.25 s was a compromise achieved only after extensive debate and some unpublished studies, which took place in the 1970-1972 development of the first ANSI Z136.1-1973 standard. While the blink reflex is faster, it is unreliable. The pupil reflex (pupillary constriction) is highly reliable and begins within 0.1 s, but requires as much as a full second for complete constriction. Cognitive decisions to avoid staring at a bright object can even take longer. For this reason, the ANSI committee evaluated the slow temporal dependence of the thermal injury thresholds and finally decided that a 0.25 s duration for the time basis of Class 2 provided a substantial and reasonable safety margin to preclude retinal injury. It must be remembered that someone can always consciously overcome their aversion response and forcefully stare at a bright source (as occurs when one stares at a solar eclipse) with the unprotected eye (eclipse blindness), which fortunately is extremely rare. Some recent studies of the blink reflex in Germany again show that the blink reflex will not consistently respond to a laser irradiation of the eye, and unfortunately, some have apparently misinterpreted the meaning of the aversion response and thought that the blink reflex alone was the basis for establishing Class 2.

The choice of the $V(\lambda)$ spectral response function as the basis of an objective criterion must also be reconsidered. It is well documented that the blue end of the visual spectrum produces a stronger pupillary stimulus and there is some evidence that discomfort glare also is stronger at shorter wavelengths. Vision research by Bouma and others in the 1960s showed that the scotopic (rod, night-vision) spectral response

$V'(\lambda)$, which peaks at 500 nm (see Figure H1), is more relevant to the pupillary response, (and probably the discomfort-glare aspect of the aversion response) if the entire retina is flooded with light. However, Alpern and Benson showed that if the central 1° (17.5 mrad) of visual space, corresponding to the 300 μm fovea, were to be stimulated, the photopic $V(\lambda)$ function served as the action spectrum for the pupillary response. This would be expected, since the fovea is dominated by cones (daylight, color-vision) receptors. If the visual stimulus (the light source) subtends a much larger angle of 8° (140 mrad), the action spectrum was shown by Alpern and Campbell to be the mean of the photopic $V(\lambda)$ and scotopic $V'(\lambda)$ functions. They also showed that a pure photopic response could only be obtained, even for a central 1° stimulus only when the rod response was saturated by background illumination. Otherwise a rod response was stimulated by scatter of light within the eye and the response was a combination of the photopic $V(\lambda)$ and scotopic $V'(\lambda)$ functions. Ocular exposure to lasers at levels sufficient to activate an aversion response will always excite the cone response and intraocular scatter will be very significant. Clearly, even for the small angular subtense values characteristic of laser sources, the pupil response will be a combination of the photopic and scotopic functions for low-to- moderate ambient lighting and photopic for higher ambient conditions.

H5. Product labeling.

The terms visible and invisible are used in a number of labels and in user information required by laser safety standards. At present, the FDA/CDRH Federal Laser Standard requires the use of the word invisible for wavelengths greater than 710 nm. When the term invisible laser radiation is used on a label located on an alexandrite laser emitting at 800 nm, and yet the beam can be seen by the user, some confusion has arisen.

The product standards are currently under review, and clearly it would be desirable to allow some flexibility in labeling in this regard. Perhaps alternative wording such as, “poorly visible radiation,” or “weakly visible radiation,” rather than invisible radiation should be permitted at the discretion of the manufacturer.

H6. Conclusions.

Several actions should be taken to harmonize the terminology referring to visible radiation and light. All laser safety standards and related literature should carefully avoid suggesting that only the 400-700 nm spectral band is visible. A greater understanding of

the transient effects of visible light is probably required in the laser safety community. This is particularly important now that ANSI Z136.6 addresses the visual disturbances from bright laser light and how this varies with wavelength in a quite different manner from injurious effects upon the retina. While spectral band designations such as visible, IR-A and UV-A are useful shorthand notations, it is important for all to recognize that their borderline wavelengths do not represent a step function for visual response or for any other photobiological effect. Indeed, to emphasize this point, the CIE for a long time applied an overlap between UV-A and "light," where UV-A extended to 400 nm and light (visible radiation) extended from about 360-400 nm to at least 780 nm.

With regard to the wavelength extent of Class 2, more consistent borders are called for. Both the short- and long-wavelength borderlines should be set at levels of equal visual sensitivity. The $V(\lambda)$ function varies strongly with wavelength with a shift of only 10-50 nm. The border wavelengths could be reset at 410 and 720 nm where $V(\lambda)$ is approximately 0.001 or at 430 and 685 nm where $V(\lambda)$ is approximately 0.01. On the other hand, considering the role of rod photoreceptors in the pupillary response for the peripheral retina (or at low ambient luminance levels), we should compare points on the $V'(\lambda)$ scotopic function, which is shifted to the blue (see Figure H1). Under accidental laser exposure conditions in the dark (or by peripheral illumination), the rod function may be important as well. The 0.01 points on the scotopic function occur at approximately 400 and 615 nm. If both functions are shown to play a role, it would appear that only the red end of the 400-700 nm band could be of real concern for the Class 2 definition.

We fully recognize that the resistance to even a small change from the current borderline wavelengths of 400 and 700 nm would meet with considerable resistance since a wavelength shift of 10-30 nm may seem insignificant on the surface. Extensive coordination among standards bodies would be required for international uniformity. Furthermore, the reliance on the $V(\lambda)$ function at these small values of visual sensitivity may not be fully justified. Even a small amount of rod contribution to the aversion response would shift the relative band to the blue, and the 400-700 nm band could be shown to be more reasonable than we have just stated. There may be other visual or neural pathways that come into play in effecting the aversion response that are not yet fully recognized. For example, Lucas *et al.* have reported the existence of a different photopigment

with a shorter peak than 550 nm that may be responsible for the pupillary response in mice. We therefore recommend some research studies of the aversion response, emphasizing pupillary closure in the 400-440 and 650-700 nm spectral regions using laser light. Some studies along this line are now underway.

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Appendix I

Sample Report Format

This report format may be used to report laser system parameters and safety information about a particular foreign military laser system to be used on a laser range owned and operated by another country that is a member of the North Atlantic Treaty Organization (NATO). This report format was modified from the draft STANAG 3606, edition 6.

11. System Identification.

This section of the report should contain a brief explanation of the intended use of the laser system on the host nation's range. It should provide enough information to identify the application (for example, laser range finder) and precisely which type of laser system is to be used. The data should include the device name, nomenclature, model number, series number or any other information to positively identify the device, i.e., its status (Prototype, Development, In-Service).

12. Operational Safety Information.

This section should provide the appropriate characteristics of the laser and the hazard distances to demonstrate that the system has been evaluated in accordance with this STANAG. The information on laser characteristics and hazard distance is the core of any hazard analysis and the visiting nation should endeavor to provide as much detail as possible. The visiting nation should provide at least the following information:

- a. Laser hazard classification.
- b. Laser safety standard used and date calculated.
- c. Reference to the laser hazard assessment document and date. The reference number of the original or current laser safety document for the system.
- d. Wavelength.
- e. Laser Beam Pointing Accuracy. The accuracy is defined as, "The full cone angle within which the laser beam can be maintained for 95% of the time". This information is needed to establish the buffer zone (see 3.3.6).
- f. Buffer Angle (x mrad for safety margin).
- g. NOHD (in meters) with and without consideration of magnifying optics (10×50).
- h. Diffuse Reflection Hazard Zone. The zone is that space within which a 100% reflecting Lambertian target will cause a hazard.

i. Skin hazard distance (in meters) to be given if there is an identifiable skin hazard, otherwise state NO SKIN HAZARD.

j. Contact name and address. The contact name should be that of the author or custodian of the laser hazard assessment or a competent person with sufficient knowledge to analyze and answer further questions.

k. Laser eye protection [Optical Density $D(\lambda)$]:

(1) $D(\lambda)$ for unaided viewing at the laser output

(2) $D(\lambda)$ for 50 mm aided viewing at the laser output

(3) $D(\lambda)$ for total beam collection at the laser output

13. Additional Data.

Further information may be provided at the discretion of the participating nations.

a. Continuous Wave (CW) or Pulse Repetition Frequency (PRF) in Hz

b. Exit Beam Diameter, a , (at $1/e$ -peak-radiant-exposure-points or at $1/e$ peak-irradiance-points) in meters

c. Exit Beam Divergence, ϕ , (at $1/e$ -peak-radiant-exposure-points or at $1/e$ peak-irradiance-points) in mrad

d. Laser Beam Pointing Accuracy

e. A brief description of how the MPEs were determined and the MPE values in $J\ m^{-2}$ or $W\ m^{-2}$ for eyes or skin.

14. System Safety Information.

a. System Safety Design Features. This section should describe safety devices for normal operation as well as during any built-in testing. These devices could include key locks, power switches, protected trigger switches, warning labels, indicator lights (for ON, armed, firing, etc). For indirect aiming systems, a description of software safety features, which are

present when maintenance may be performed in the field environment.

b. System Safety Design Checks. This section should describe a check of the laser output for unwanted emissions such as hazardous secondary beams and opacity of beam blocks and covers. Also, identify checks for activation after the system has been turned OFF and stray emissions during any internal tests such as bore-sighting.

c. Operational Tactics. Flight profile, etc., for airborne lasers and maneuver plan for surface lasers. This information is needed to establish the laser hazard footprint.

d. Operators Proficiency Level. Nations are to consider the proficiency and state of training of laser operators and their familiarity with the specific range involved.

15. Other Health and Safety Information.

This section should cover any other factors not mentioned in the sections above, which could have an affect on general health and safety or the environment in the area around the host nation's range. These factors include possible hazards from general use of the system and potential hazards in the event of an accident. Such factors might include the use of gases or other chemicals, radioactive materials, high voltages, or hazardous materials used in the construction of the device. If there are no special considerations when using the laser system, the visiting nation should state NONE under this heading.



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American National Standard

The standard in this booklet is one of more than 10,000 standards approved to date by the American National Standards Institute (ANSI).

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Each standard represents general agreement among maker, seller, and user groups as to the best current practices with regard to some specific problem. Thus the completed standards cut across the whole fabric of production, distribution, and consumption of goods and services. American National Standards, by reason of Institute procedures, reflect a national consensus of manufacturers, consumers, and scientific, technical, and professional organizations, and government agencies. The completed standards are used widely by industry as well as commerce and often by municipal, state, and federal governments.

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