

ANSI Z136.8 – 2012

American National Standard

*American National Standard
for Safe Use of Lasers in
Research, Development, or Testing*

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**Laser Institute
of America**
Laser Applications and Safety



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**American National Standard
for Safe Use of Lasers in
Research, Development, or Testing**

**Secretariat
Laser Institute of America**

**Approved: April 3, 2012
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**American
National
Standard**

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Foreword (This introduction is not a normative part of ANSI Z136.8-2012, *American National Standard for Safe Use of Lasers in Research, Development, or Testing*.)

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 the ANSI Accredited Standards Committee (ASC) Z136 for Safe Use of Lasers. A copy of the procedures for development of these standards can be obtained from the secretariat, Laser Institute of America, 13501 Ingenuity Drive, Suite 128, Orlando, FL 32826 or viewed at www.z136.org.

The present scope of ASC Z136 is to protect 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 and an editorial working group (EWG). 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
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
SSC-8	Safe Use of Lasers in Research, Development, or Testing
SSC-9	Safe Use of Lasers in Manufacturing Environments
SSC-10	Safe Use of Lasers in Entertainment, Displays, and Exhibitions
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 seven standards currently issued are:

ANSI Z136.1-2007, *American National Standard for Safe Use of Lasers* (replaces ANSI Z136.1-2000)

ANSI Z136.3-2011, *American National Standard for Safe Use of Lasers in Health Care* (replaces ANSI Z136.3-2005 *American National Standard for Safe Use of Lasers in Health Care Facilities*)

ANSI Z136.4-2010, *American National Standard Recommended Practice for Laser Safety Measurements for Hazard Evaluation* (replaces ANSI Z136.4-2005)

ANSI Z136.5-2009, *American National Standard for Safe Use of Lasers in Educational Institutions* (replaces ANSI Z136.5-2000)

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

ANSI Z136.7-2008, *American National Standard for Testing and Labeling of Laser Protective Equipment* (first edition)

ANSI Z136.8-2012, *American National Standard for Safe Use of Lasers in Research, Development, or Testing* (first edition)

This American National Standard is intended to ensure the safe use of lasers in research, development, or testing environments, and has been published as part of the ANSI Z136 series of laser safety standards. The base document of the series is the American National Standard for Safe Use of Lasers, ANSI Z136.1. The procedures and methodologies described in this standard are based on requirements previously established in ANSI Z136.1 and are intended to give more specific processes for accomplishing laser safety in a research, development, or testing settings. The purpose of this standard is to give more specific user guidance for accomplishing laser safety for individuals with the potential for laser exposure in the research, development, or testing setting. It should be recognized that the scope of the ANSI Z136.8 includes all circumstances when people may be exposed to laser radiation as part of research, development, and testing applications. This standard includes policies and procedures to ensure laser safety in any area where research, development, and testing is performed, including Universities, product development labs, private and government research labs (e.g., National Laboratories), and product testing settings. In general, this standard may be used independently of ANSI Z136.1; however, instances where additional guidance contained in ANSI Z136.1 is required are noted in the text of this document. The body of this standard is a normative standard that applies to all research, development, and testing settings that use lasers. The appendices, excluding Appendix A, are informative providing examples and discipline specific supplementary information.

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 highly recommended.

While there is considerable compatibility among existing laser safety standards, some requirements differ among state, federal, and international standards and regulations. These differences may have an effect on the particulars of the applicable control measures.

Occasionally questions may arise regarding the meaning or intent of portions of this standard as it relates to specific applications. When the need for an interpretation is brought to the attention of the secretariat, the secretariat will initiate action to prepare an appropriate response. Since ANSI Z136 standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, the secretariat is not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration. Requests for interpretations and suggestions for improvements of the standard are welcome. They should be sent to ASC Z136 Secretariat, Laser Institute of America, 13501 Ingenuity Drive, Suite 128, Orlando, FL 32826.

This standard was processed and approved for submittal to ANSI by ASC Z136. Committee approval of the standard does not necessarily imply that all members voted for its approval.

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Notice

(This notice is not a normative part of ANSI Z136.8-2012, *American National Standard for Safe Use of Lasers in Research, Development, or Testing*.)

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 in Research, Development, or Testing

1. General

1.1 Scope.

This standard provides recommendations for the safe use of lasers and laser systems that operate at wavelengths between 180 nm and 1000 μm and are used to conduct research or used in a research, development, or testing environment.

1.2 Application.

The objective of this standard is to provide reasonable and adequate guidance for the safe use of lasers and laser systems in research, development, and testing environments, where safety controls common for commercial lasers may be either missing (nonexistent) or disabled. Similarly, in testing environments, lasers or laser systems may be operated in conditions or protocols different from normal operation, including access to levels of radiation higher than the accessible emission limits (AEL) for the assigned product class.

Typically, this objective is accomplished by first classifying the laser and laser systems according to their relative hazards and then by specifying appropriate control measures based upon their relative hazards and conditions of use. In most cases, this procedure eliminates the need for laser radiation measurements, quantitative analysis of hazard potential, or the use of point or extended source maximum permissible exposure (MPE) values.

The ANSI Z136.1 standard supports this application-specific standard by providing the quantitative methods for hazard analysis and the MPE values for optical radiation exposure. Other application-specific standards within the ANSI Z136 series may deviate from the requirements of this standard. It is the responsibility of the Laser Safety Officer (LSO) to review and use the applicable standards in the series for their actual condition of use.

It may be necessary to utilize the requirements from several standards in the ANSI Z136 series to achieve proper hazard control for the intended condition of use in a research, development, or testing environment. For example, an outdoor laser research activity may require application of both the ANSI Z136.6 and Z136.8 standard control measures in order to mitigate potential hazards.¹

The basis of the hazard classification scheme in Section 3 of this standard is the ability of the laser to cause biological damage to the eye or skin. Non-beam hazards, e.g., electrical hazards, must be controlled, but are not considered within the hazard classification scheme. Individuals shall refer to ANSI Z136.1 for the current hazard classifications, MPE values for ocular and skin exposure, as well as quantitative hazard analysis calculation methods. The

¹ When the year of publication is shown, the reference is to that specific standard; when the year of publication is not shown, it means the latest revision of that standard.

tables and figures that are included in this document are provided solely as a convenience for the user.

In this standard, testing includes:

- a) Measurement, evaluation, or assessment of any properties or parameters (such as power, energy, beam size, divergence, shape, wavelength or spectral range, pulse duration, and pulse repetition frequency) of the laser radiation emitted by any type of laser, laser system, or laser product in any conditions or operation, maintenance or service.
- b) Verification of the functionality of any laser safety features such as protective housing interlocks, interlock override procedures, emission indicators, beam stops or attenuators, remote interlock connections, and operation controls.
- c) Verification of the overall functionality of any laser, laser system, or laser product to determine if it meets the performance specifications for its intended application, including experimental runs.
- d) Operation of laser products or equipment, where the laser radiation is the "tool" for non-contact tests and measurements, e.g., dimensions and physical properties.

1.3 Laser Safety Programs.

1.3.1 General. The corporate or institutional (supervising) management (employer) has the fundamental responsibility to ensure the safe use of lasers owned and/or operated in facilities under its control, and shall establish and maintain an adequate program for the control of laser hazards.

The following guidelines for laser safety programs contain requirements (designated by *shall*) and recommendations (designated by *should* or *preferred*). In the case of recommendations, employers should perform a hazard evaluation based upon the laser, the beam path, the laser process interactions, the location, and the personnel using the laser. The evaluation could consider the likelihood of using viewing optics, and the intentional or unintentional misuse of a laser that would not normally be hazardous. In many instances, an employer would not need to implement a recommendation; however, in other instances, it may be useful or prudent to implement the recommendation to assure the safe use of lasers for a specific application.

Employer and/or facility safety programs and employee training programs shall be provided for Class 3B or Class 4 lasers and laser systems. Employer and/or facility safety programs and employee training should be provided for laser systems containing embedded Class 3B and Class 4 lasers. Employer and/or facility safety programs and employee training programs are not required for Class 1 lasers and laser systems that do not contain embedded Class 3B or Class 4 lasers.

1.3.2 Laser Safety Program Provisions. The laser safety program established by the employer shall include the following provision:

- a) Designate an individual as the Laser Safety Officer (LSO) with the authority and responsibility to evaluate and control laser hazards, to implement appropriate control measures, and to monitor and enforce compliance with required standards and regulations. The specific duties and responsibilities of the LSO are designated in

normative Appendix A of ANSI Z136.1 and this standard. (Note that a normative appendix is an extension of the standard, and as such is an integral part of the standard.) Throughout the body of this standard, it shall be understood that wherever duties or responsibilities of the LSO are specified, it will mean that the LSO either performs the stated task or assures that the task is performed by qualified individual(s). Such duties and tasks include the following:

1. Educate authorized personnel (LSOs, operators, service personnel, and others) in the safe use of lasers and laser systems, and as applicable, the assessment and control of laser hazards through training programs. Employers should consider providing awareness training for employees working with and around lasers and laser systems greater than Class 1. If an employer requires training for embedded lasers, it shall include not only operators but also those who routinely work around the systems, and/or who will be present when maintenance requiring beam access or service occurs. The employer must be aware that staff involved in research, development, and testing may have a greater risk of laser radiation exposure than that of a routine laser user in an industrial setting.
2. Apply adequate protective measures for laser hazard control as required in Section 4.
3. Conduct incident investigation including reporting of alleged accidents to the LSO, and prepare action plans for the prevention of future accidents following a known or suspected incident.
4. Consider implementing an appropriate medical examination and medical surveillance program according to Section 6 in ANSI Z136.1.
5. Consider forming a Laser Safety Committee when the number, hazards, complexity, and/or diversity of laser activities warrants. The structure and responsibilities for a Laser Safety Committee are presented in Appendix A.

1.3.3 Personnel Responsibilities. The LSO should identify the different laser user(s) at their facility based upon function, activities, and the probability for exposure to optical radiation and non-beam hazards. The employer's written laser safety program needs to delineate the responsibilities and expectations required for each type of identified user to comply with the provisions of the program.

1.3.3.1 Employees who work with lasers or laser systems and their supervisors assume primary responsibility for the safe use of the lasers or laser systems they operate and control. Suggested responsibilities for these individuals are provided in Appendix A.

1.3.3.2 The LSO should develop, document, and enforce the laser safety program, and provide training and expertise to individuals identified in the program. Refer to Appendix A in both ANSI Z136.1 and this standard for additional discussion of the duties and responsibilities of the LSO.

1.3.3.3 Procurement agents or other individuals designated by the employer to review and approve laser and laser system purchases should contact the LSO to aid in the implementation of the laser safety program.

1.3.3.4 Individuals fabricating, altering or installing a Class 3B or Class 4 laser or laser system, or a system incorporating an embedded Class 3B or Class 4 laser, should contact the LSO prior to energizing any such laser or laser system to aid in the implementation of the laser safety program.

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 appendixes and are in no way 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.

administrative controls. Control measures incorporating administrative means (e.g., training, safety approvals, LSO designation, and Standard Operating Procedures [SOP]) to mitigate the potential hazards associated with laser use.

alpha max. The angular subtense of an extended source beyond which additional subtense does not contribute to the hazard and need not be considered. This value is 100 mrad for retinal thermal effects and 110 mrad for the retinal photochemical effects. Symbol: α_{\max}

alpha min. The angular subtense of a source below which the source can be effectively considered as a point source. The value of alpha min is 1.5 mrad. Symbol: α_{\min}

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

apparent visual angle. The angular subtense (α) of the source as calculated from source size and distance from the eye. It is not the beam divergence of the source.

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

authorized personnel. Individuals approved by management to operate, maintain, service, or install laser equipment.

average power. The total energy in an exposure or emission divided by the duration of the exposure or emission.

aversion response. Closure of the eyelid, eye movement, pupillary constriction, or movement of the head to avoid an exposure to a noxious or bright light stimulant. In this standard, the aversion response to an exposure from a bright, visible, laser source is assumed to limit the exposure of a specific retinal area to 0.25 seconds or less.

beam. A collection of light/photonic rays characterized by direction, diameter (or cross-section dimensions), and divergence (or convergence) angle.

beam diameter. The distance between diametrically opposed points in that cross-section of a beam where the power per unit area is $1/e$ (0.368) times that of the peak power per unit area.

C_A . Correction factor that increases the MPE in the near infrared (IR-A) spectral band (700-1400 nm) based upon reduced absorption properties of melanin pigment granules found in the skin and in the retinal pigment epithelium.

C_B . Correction factor that increases the MPE in the red end of the visible spectrum (450-600 nm), because of greatly reduced photochemical hazards.

C_C . Correction factor that increases the MPE for ocular exposure because of pre-retinal absorption of radiant energy in the spectral region between 1150 and 1400 nm.

C_E . Correction factor used for calculating the extended source MPE for the eye from the point source MPE.

C_P . Correction factor that reduces the MPE for repetitive pulse exposure of the eye.

carcinogen. An agent potentially capable of causing cancer.

certified laser. A laser product that has been built to the laser product performance standard (CFR 29, part 1040.1) and such documentation has been submitted to the CDRH.

coagulation. The process of congealing by an increase in viscosity characterized by a condensation of material from a liquid to a gelatinous or solid state.

coherent. A beam of light characterized by a fixed phase relationship (spatial coherence) or single wavelength, i.e., monochromatic (temporal coherence).

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

collecting optics. Lenses or optical instruments having magnification and thereby producing an increase in energy or power density. Such devices may include telescopes, binoculars, microscopes, or loupes.

NOTE—Normal or prescription eyewear is not considered collecting optics.

collimated beam. Effectively, a “parallel” beam of light with very low divergence or convergence.

Condition 1. Pertains to optically aided viewing of collimated beams through telescopes or binoculars.

Condition 2. Pertains to optically aided viewing of sources with highly divergent beams through magnifiers or eye loupes or unaided viewing with or without strong accommodation.

NOTE—Condition 2 has slightly different measurement conditions in IEC 60825-1.²

continuous wave (CW). In this standard, a laser operating with a continuous output for a period ≥ 0.25 seconds is regarded as a CW laser.

controlled area (laser). 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.

controlled location. An area where the access, occupancy, and activities of people within are subject to strict control and supervision. By inference, controlled locations are restricted locations with laser radiation hazards at Class 4 with additional control measures specified by the laser operator, the LSO, and the employer management.

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

critical frequency. The pulse repetition frequency above which the laser output is considered continuous wave (CW). For example, for a short unintentional exposure (0.25 s to 10 s) to nanosecond (or longer) pulses, the critical frequency is 55 kHz for wavelengths between 400 and 1050 nm, and 20 kHz for wavelengths between 1050 and 1400 nm.

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

divergence. 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.

Symbol: ϕ

effective energy. Energy, in joules, through the applicable measurement aperture.

Symbol: Q_{eff}

² IEC 60825-1, Safety of laser products - Part 1: Equipment classification and requirements, International Electrotechnical Commission, Geneva.

effective power. Power, in watts, through the applicable measurement aperture.
Symbol: Φ_{eff}

electromagnetic radiation. The flow of energy consisting of orthogonally vibrating electric and magnetic fields lying transverse to the direction of propagation. Gamma rays, X-ray, ultraviolet, visible, infrared, and radio waves occupy various portions of the electromagnetic spectrum and differ only in frequency, wavelength, and photon energy.

embedded laser. An enclosed laser that has a higher classification than the laser system in which it is incorporated, where the system's lower classification is appropriate due to the engineering features limiting accessible emission.

enclosed laser. A laser that is contained within a protective housing of itself or of the laser or laser system in which it is incorporated. Opening or removing of the protective housing provides additional access to laser radiation above the applicable MPE than possible with the protective housing in place (an embedded laser is an example of one type of enclosed laser).

engineering controls. Methods of protecting others from exposure to laser radiation that requires no training on the behalf of those who may be exposed, e.g., interlocks and barriers.

energy. The capacity for doing work. Energy content is commonly used to characterize the output of pulsed lasers. Unit: joules (J). Symbol: Q

epithelium (of the cornea). The layer of cells forming the outer surface of the cornea.

erythema. For the purposes of the standard, redness of the skin due to exposure to laser radiation.

exclusion location. An area where occupancy by people is possible but is denied by the LSO during the operation of the laser system.

extended source. A source of optical radiation with an angular subtense at the cornea larger than α_{min} . See also *point source*.

eye-safe laser. A Class 1 laser product. Because of the frequent misuse of the term "eye-safe wavelength" to mean "retina-safe," (e.g., at 1.5-1.8 μm) and *eye-safe laser* to refer to a laser emitting at wavelengths outside the retinal hazard region, the term "eye-safe" can be a misnomer. Hence, the use of *eye-safe laser* is discouraged.

fail-safe interlock. An interlock where the failure of a single mechanical or electrical component of the interlock will cause the system to go into, or remain in, a safe mode.

field of view. The full solid angle from which a detector's active area receives radiation.

focal length. The distance from the secondary nodal point of a lens to the secondary focal point. For a thin lens imaging a distant source, the focal length is the distance between the lens and the focal point.

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

half-power point. The point on either the leading or trailing edge of a laser pulse at which the power is one-half of its maximum value.

hertz (Hz). The unit that expresses the frequency of a periodic oscillation in cycles per second.

inaccessible location. An area where occupancy is not possible due to its dimensions.

infrared radiation. Electromagnetic radiation with wavelengths that lie within the range 700 nm to 1 mm.

installation. Placement and connection of laser equipment at the appropriate site to enable intended operation.

integrated radiance. The integral of the radiance over the exposure duration, expressed in joules-per-centimeter-squared per-steradian ($\text{J}\cdot\text{cm}^{-2}\cdot\text{sr}^{-1}$).

intrabeam viewing. The viewing condition whereby the eye is exposed to all or part of a laser beam.

iris. The circular pigmented structure that lies between the aqueous and lens of the human eye. The iris is perforated by the pupil.

irradiance. Radiant power incident per unit area upon a surface, expressed in watts-per-centimeter-squared ($\text{W}\cdot\text{cm}^{-2}$). Symbol: E

joule (J). A unit of energy. 1 joule = 1 Newton-meter; 1 joule = 1 watt • second.

Lambertian surface. An ideal (diffuse) surface whose emitted or reflected radiance is independent of the viewing angle.

laser. A device that produces radiant energy predominantly by stimulated emission. Laser radiation may be highly coherent spatially, temporally, or both. An acronym for Light Amplification by Stimulated Emission of Radiation.

laser barrier. A device used to block or attenuate to safe levels incident, direct, or diffuse laser radiation. Laser barriers are frequently used during times of service to the laser system when it is desirable to establish a boundary for a controlled laser area.

laser classification. An indication of the beam hazard level of a laser or laser system during normal operation. The hazard level of a laser or laser system is represented by a number

or a numbered capital letter. The laser classifications are Class 1, Class 1M, Class 2, Class 2M, Class 3R, Class 3B, and Class 4. In general, the potential beam hazard level increases in the same order.

laser diode. A laser employing a forward-biased semiconductor junction as the active medium.

laser personnel. Persons who routinely work around hazardous laser beams. This standard requires such persons to be protected by engineering controls and administrative procedures.

laser pointer. A laser product that is usually hand held that emits a low-divergence visible beam and is intended for designating specific objects or images during discussions, lectures, or presentations as well as for the aiming of firearms or other visual targeting practice. These products are normally Class 2 or Class 3R.

laser safety officer (LSO). One who has authority and responsibility to monitor and enforce the control of laser hazards and effect the knowledgeable evaluation and control of laser hazards.

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

lesion. An abnormal change in the structure of an organ or part due to injury or disease.

limiting angular subtense. See *alpha min*.

limiting aperture diameter. The diameter of a circle over which irradiance or radiant exposure is averaged for purposes of hazard evaluation and classification. Symbol: D_f

limiting cone angle. The cone angle through which radiance or integrated radiance is averaged when photochemical effects are considered in hazard evaluation and classification. Symbol: γ

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

macula. The small uniquely pigmented specialized area of the retina of the eye, which, in normal individuals, is predominantly employed for acute central vision (i.e., area of best visual acuity).

magnified viewing. Viewing a small object through an optical system that increases the apparent object size. This type of optical system can make a diverging laser beam more hazardous (e.g., using a magnifying optic to view an optical fiber emitting a laser beam).

maintenance. Performance of those adjustments or procedures (specified in the user information provided by the manufacturer, and considered preventative to maintain optimal performance of the laser system) that are to be carried out by the user to ensure

the intended performance of the product. It does not include *operation* or *service* as defined in this section.

maximum permissible exposure (MPE). The level of laser radiation to which an unprotected person may be exposed without adverse biological changes in the eye or skin.

measurement aperture. The aperture used for classification of a laser to determine the effective power or energy that is compared with the AEL for each laser hazard class.

meter. A unit of length in the international system of units; currently defined as the length of a path traversed in a vacuum by light during a period of 1/299792458 seconds. Typically, the meter is subdivided into the following units:

centimeter (cm)	=	10^{-2} m
millimeter (mm)	=	10^{-3} m
micrometer (μ m)	=	10^{-6} m
nanometer (nm)	=	10^{-9} m

minimum viewing distance. The minimum distance at which the eye can produce a focused image of a diffuse source, usually assumed to be 10 cm.

monochromatic light. Having or consisting of one color or wavelength.

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

nominal ocular hazard distance (NOHD). The distance along the axis of the unobstructed beam from a laser, fiber end, or connector to the human eye beyond which the irradiance or radiant exposure is not expected to exceed the applicable MPE.

non-beam hazard. A class of hazards that result from factors other than direct human exposure to a laser beam.

normative appendix. An appendix that contains information required to implement the standard and is therefore officially part of the standard. Normative appendixes are placed after the body of the standard for reasons of convenience or to create a hierarchical distinction.

ocular fundus. The concave interior of the eye consisting of the retina, the choroid, the sclera, the optic disk, and blood vessels as seen upon ophthalmoscopic examination.

OEM. Original equipment manufacturer.

open beam path. A laser beam path where any portion of the beam is accessible without defeating an engineering control.

operation. The performance of the laser or laser system over the full range of its intended functions (normal operation). It does not include *maintenance* or *service* as defined in this section.

ophthalmoscope (funduscope). An instrument for examining the interior of the eye.

optically aided viewing. Viewing with a telescopic (binocular) or magnifying optic. Under certain circumstances, viewing with an optical aid can increase the hazard from a laser beam. See *magnified viewing* and *telescopic viewing*.

optical density. The logarithm to the base ten of the reciprocal of the transmittance at a particular wavelength:

$$OD = \log_{10} (1/\tau_\lambda)$$

where τ_λ is the transmittance at the wavelength of interest. Symbol: OD, $D(\lambda)$, or D_λ .

photochemical effect. A biological effect produced by a chemical action brought about by the absorption of photons by molecules that directly alter the molecule.

photosensitizers. Substances that increase the sensitivity of a material to exposure by optical radiation.

pigment epithelium (of the retina). The layer of cells that contain brown or black pigment granules next to and behind the rods and cones.

plasma radiation. Black-body radiation generated by luminescence of matter in a laser generated plume.

point source. For purposes of this standard, a source with an angular subtense at the cornea equal to or less than alpha-min (α_{\min}), i.e., ≤ 1.5 mrad.

point source viewing. The viewing condition whereby the angular subtense of the source, α , is equal to or less than the limiting angular subtense, α_{\min} .

power. The rate at which energy is emitted, transferred, or received. Unit: watts (W); 1 watt = 1 joule-per-second.

procedural controls. Methods or instructions that specify rules, or work practices, or both, that implement or supplement engineering controls and which may specify the use of personal protective equipment.

protective housing. An enclosure that surrounds the laser or laser system and prevents access to laser radiation above the applicable MPE. The aperture through which the useful beam is emitted is not part of the protective housing. The protective housing limits access to other associated radiant energy emissions and to electrical hazards associated with components and terminals, and may enclose associated optics and a workstation.

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. Typical units:

microsecond (μs)	=	10^{-6} s
nanosecond (ns)	=	10^{-9} s
picosecond (ps)	=	10^{-12} s
femtosecond (fs)	=	10^{-15} s

Symbol: t

pulse-repetition frequency (PRF). The number of pulses occurring per second, expressed in hertz. Symbol: F

pulsed laser. A laser that delivers its energy in the form of a single pulse or a train of pulses. In this standard, the duration of a pulse is less than 0.25 s.

pupil. The variable aperture in the iris through which light travels to the interior of the eye.

Q-switch. A device for producing very short (~ 10 -250 ns), intense laser pulses by enhancing the storage and dumping of energy in and out of the lasing medium, respectively.

Q-switched laser. A laser that emits short (~ 10 -250 ns), high-power pulses by means of a Q-switch.

radian (rad). A unit of angular measure equal to the angle subtended at the center of the circle by an arc whose length is equal to the radius of the circle (sr). 1 radian ~ 57.3 degrees; 2π radians = 360 degrees.

radiance. Radiant flux or power output per unit area per unit solid angle expressed in watts-per-centimeter squared per-steradian ($\text{W}\cdot\text{cm}^{-2}\cdot\text{sr}^{-1}$). Symbol: L

radiant energy. Energy emitted, transferred, or received in the form of radiation. Unit: joules (J). Symbol: Q

radiant exposure. Surface density of the radiant energy received. Unit: joules-per-centimeter squared ($\text{J}\cdot\text{cm}^{-2}$). Symbol: H

radiant flux. Power emitted, transferred, or received in the form of radiation. Unit: watts (W). Symbol: Φ . Synonym: *radiant power*.

radiant power. Power emitted, transferred, or received in the form of radiation. Unit: watts (W). Symbol: Φ . Synonym: *radiant flux*.

radiometry. For the purposes of this standard, the measurement of infrared, visible, and ultraviolet radiation.

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

reflection. Deviation of radiation following incidence on a surface.

refraction. The bending of a beam of light in transmission through an interface between two dissimilar media or in a medium whose refractive index is a continuous function of position (graded index medium).

refractive index (of a medium). The ratio of the velocity of light in a vacuum to the phase velocity in the medium. Symbol: n

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

restricted location. An area where access is granted for authorized people and limited for the general public through administrative and engineering control measures. Laser radiation hazards at Class 3B levels or greater may be present and control measures are required. Administrative controls include posted warning signs, attending training, and following established standard operating procedures (SOPs) for laser system(s). Engineering controls include access control measures such as lockable doors, barriers, defeatable interlocks, and curtains to prevent laser radiation from leaving the restricted location.

retina. The sensory tissue that receives the incident image formed by the cornea and lens of the human eye.

retinal hazard region. Optical radiation with wavelengths between 400 and 1400 nm, where the principal hazard is usually to the retina.

safety latch. A mechanical device designed to require a conscious decision to override to gain entry into a controlled area.

scanning laser. A laser having 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.

secured enclosure. An enclosure to which casual access is impeded by an appropriate means, e.g., a door secured by a magnetically or electrically operated lock or latch, or by fasteners that need a tool to remove.

service. The performance of procedures, typically defined as repair, to bring the laser or laser system or laser product back to full and normal operational status. It does not include *operation* or *maintenance* as defined in this section.

shall. The word *shall* is to be understood as mandatory.

should. The word *should* is to be understood as advisory.

solid angle. The three-dimensional angular spread at the vertex of a cone measured by the area intercepted by the cone on a unit sphere whose center is the vertex of the cone. Unit: steradian (sr).

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

spectator. An individual who wishes to observe or watch a laser or laser system in operation, and who may lack the appropriate laser safety training.

specular reflection. A mirror-like reflection.

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

standard operating procedure (SOP). Formal written description of the safety and administrative procedures to be followed in performing a specific task.

T_1 . The exposure duration (time) at which MPEs based upon thermal injury are replaced by MPEs based upon photochemical injury to the retina.

T_2 . The exposure duration (time) beyond which extended source MPEs based upon thermal injury are expressed as a constant irradiance.

T_{\max} . The total expected or anticipated exposure duration. T_{\max} may differ depending upon its use.

telescopic viewing. Viewing an object from a long distance with the aid of an optical system that increases the visual size of the image. The system (e.g., binoculars) generally collects light through a large aperture thus magnifying hazards from large-beam, collimated lasers.

testing. The act of measurement, evaluation, verification or assessment of any properties or parameters of a laser or laser system, i.e., life time test or beam specifications.

thermal effect. An effect brought about by the temperature elevation of a substance due to laser exposure.

threshold limit (TL). An expression of the “resistance factor” for beam penetration of a laser protective device, i.e., the maximum average irradiance or radiant exposure at a given beam diameter for which a laser protective device provides adequate beam resistance. Thus, laser exposures delivered on the protective device (e.g., laser protective eyewear filters, protective windows, and barriers) at or below the TL will limit beam penetration to levels at or below the applicable MPE. Unit: $\text{W}\cdot\text{cm}^{-2}$ or $\text{J}\cdot\text{cm}^{-2}$.

t_{\min} . For a pulsed laser, the maximum duration for which the MPE is the same as the MPE for a 1 ns exposure. For thermal biological effects, this corresponds to the “thermal confinement duration” during which heat flow does not significantly change the absorbed energy content of the thermal relaxation volume of the irradiated tissue.

transmission. Passage of radiation through a medium.

transmittance. The ratio of transmitted power (energy) to incident power (energy).

ultraviolet radiation. In this standard, electromagnetic radiation with wavelengths between 180 and 400 nm (wavelengths shorter than those of visible radiation).

uncontrolled area. An area where the occupancy and activity of those within is not subject to control and supervision for the purpose of protection from radiation hazards.

unrestricted location. An area where access is not limited. By default, no laser radiation hazards exist (Class 1), and these locations can be occupied by the general public, visitors, and spectators without implementing control measures (administrative, engineering, and personal protective equipment).

viewing window. A visually transparent part of an enclosure that contains a laser process. It may be possible to observe the laser processes through the viewing window(s).

visible radiation (light). The term is used to describe electromagnetic radiation that can be detected by the human eye. In this standard, this term is used to describe wavelengths that lie in the range 400 to 700 nm. Derivative standards may legitimately use 380 – 780 nm for the visible radiation range.

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

wavelength. The distance in the line of advance of a sinusoidal wave from any one point to the next point of corresponding phase (e.g., the distance from crest to crest or trough to trough).

work practices. Procedure(s) used to accomplish one or more tasks.

3. Hazard Evaluation and Classification

3.1 General.

A laser controlled area (LCA) is any area, permanent or temporary, that contains hazardous laser operations. Hazards associated with the laser operation must be evaluated and mitigated by the use of appropriate control measures at the boundaries of and within the LCA. Several aspects of the laser or laser system application influence the total laser hazard evaluation and the application of control measures to the laser, the equipment, and the people. In research, development, or testing environments, these aspects consist of:

- a) The capability of the laser or laser system to injure people.
- b) The beam path (e.g., in air or vacuum), its configuration (e.g., open beam, fiber optic, level of enclosure) and the factors applied to beam (e.g., non-linear optics, pulse compression, or amplification).
- c) Process interactions between the beam and materials during operation, e.g., rapid oxidation, ionizing radiation or laser generated air contaminants (LGACs).
- d) The location in which the laser is used (i.e., unrestricted, restricted, controlled, inaccessible, or exclusion).

- e) The personnel who may use or be exposed to laser radiation.

3.2 Laser Beam Path.

In the research, development, or testing setting, the parameters of the laser beam may change along its beam path. Therefore, any hazard evaluation will need to consider such changes. This can include changes in wavelength, pulse duration and accessibility to the beam.

3.2.1 Nominal Hazard Zones. The nominal hazard zone (NHZ) is that region identified and confined within the LCA in which the irradiance or radiant exposure of the laser beam may exceed the MPE. The NHZ may be the entire LCA. Every effort should be made to contain the NHZ to a smaller sub-area within the LCA using engineering controls, such as perimeter guards, enclosures, beam blocks, barriers, and curtains. When the NHZ is smaller than the LCA, the NHZ should be clearly identified and have appropriate labels or signs. The LSO may specify the implementation of control measures to protect personnel from exposure to laser radiation above the MPE within the NHZ. Calculations may indicate the NHZ is either smaller or larger than the actual LCA; for ease of operation the LSO can then define the LCA as the NHZ. The LSO shall use one of the following methods to define the NHZ:

3.2.1.1 If the laser radiation is contained within a specific location, then the specific location is defined as the NHZ.

3.2.1.2 Based upon calculations utilizing: 1) the appropriate laser range equations, and 2) the performance specifications provided by the laser or laser system manufacturer, the NHZ can be defined.

3.2.1.3 Declare the entire use area and all locations contained within as the NHZ. Control measures are required within the NHZ, which may include fully enclosing the NHZ when this area is limited in size (see Section 4.3.10 of ANSI Z136.1-2007). Viewing the main beam or a specular laser target with an optical instrument is potentially hazardous due to the instrument's light-gathering capability (see Appendixes B4.2, B6.4.3, and B6.6.3; and Examples 22-24, 45, and 53 in ANSI Z136.1-2007). Therefore, the use of such optical systems may effectively increase the NHZ boundaries and must be considered in the overall hazard analysis.

3.2.2 Indoor Laser Operations. The laser and beam path are considered when evaluating an indoor laser operation whether the beam is enclosed or operated in a restricted or controlled location. Consider all optics (e.g., lenses, mirrors, fiber optics) that are a permanent part of the beam path in this evaluation. The LSO in conjunction with the user should follow the step-by-step procedure described below when evaluating the NHZ for indoor use:

Step 1. Determine and evaluate all possible beam paths and reflections. Include multiple beam paths due to lack of fixed positioning and unintended beam paths due to unstable mounts, bearing wear, vibration and re-alignment, for example.

Step 2. Check for and contain stray reflections.

Step 3. Determine the likelihood for operation or maintenance personnel being within the LCA during operation.

Step 4. Determine whether optical aids such as eye loupes or hand magnifiers will be used within 10 cm of a highly diverging beam.

Step 5. Determine whether non-beam hazards exist.

3.2.3 Outdoor Laser Operations. Define the extent of several potentially hazardous conditions by considering all optics that are a permanent part of the beam path. The LSO should consider the guidance found in ANSI Z136.6 and follow the step-by-step procedures given below in steps 1 through 8.

Step 1. Determine the NHZ of the laser. Calculations of radiant exposure or beam irradiance as a function of range can be made with the range equation (an example can be found in Appendix B of ANSI Z136.1).

These calculated ranges are only estimates beyond a few hundred meters, since uncertainties arise from atmospheric effects (for example, scintillation due to turbulence).

Step 2. Evaluate potential hazards from transmission through windows and specular reflections. Specular surfaces ordinarily encountered (for example, windows and mirrors in vehicles and windows in buildings) are oriented vertically and will usually reflect a horizontal beam in a horizontal plane.

NOTE—As much as 8% of the beam's original irradiance or radiant exposure can be reflected toward the laser from a clear glass window that is oriented perpendicular to the beam. If the beam strikes a flat, specular surface at an angle, a much greater percentage of the beam can be reflected beyond, or to the side of, the target area. If the beam strikes a still pond or other similar surface at a grazing angle, effective reflectivity also may approach 100%. Specular reflective surfaces, such as raindrops, wet leaves, and most other shiny natural objects, seldom reflect hazardous radiant intensities beyond one meter from these reflectors.

Step 3. Determine whether hazardous diffuse reflections exist (see Table 3 and Examples 47 - 55 in Appendix B6.6 in ANSI Z136.1-2007). Determine the corresponding NHZ.

Step 4. Determine whether the beam will visually interfere with critical tasks. Refer to ANSI Z136.6 for more information on operation of visible laser systems outdoors at night.

Step 5. Evaluate the stability of the laser platform to determine the extent of lateral range control and the lateral constraints that should be placed on the beam traverse. Determine the corresponding NHZ during operation.

Step 6. Consider the likelihood of people being in the NHZ.

Step 7. Determine whether optical aids such as telescopes or binoculars could be used within or near the beam path.

Step 8. Determine if visible lasers will be used near airports at night. Levels of laser irradiance as low as $50 \text{ nW}\cdot\text{cm}^{-2}$ may be of concern. Refer to ANSI Z136.6 for the most complete guidance or the latest revision of FAA Order 7400.2 for additional guidance.

3.3 Laser Process Interactions.

In research, development, or testing, the target of laser radiation may produce non-beam hazards (ionizing radiation, LGAC). These hazards may be contained in an experimental chamber or extend beyond the target area. Awareness of such hazards and their appropriate controls shall be implemented. See section 7 – non-beam hazards for details.

3.4 Laser Use Location.

The decision by the LSO to employ additional control measures not specifically required in Section 4 of this standard, or to eliminate some that are, is influenced by location considerations for Class 3B and Class 4 lasers or laser systems. The following defines the terms and conditions for each Class 3B or Class 4 laser location:

- a) Unrestricted location: Access is not limited. By default, no laser radiation hazards exist (Class 1), and these locations can be occupied by the general public, visitors, and spectators without implementing administrative or engineering control measures, and personal protective equipment (PPE).

Example: A hallway in a building containing Class 3B and/or Class 4 lasers.

- b) Restricted location: Access is granted for authorized people and limited for the general public through administrative and engineering control measures. Laser radiation hazards at Class 3B levels or greater may be present and control measures are required. Administrative controls include posted warning signs, attending training, and following established SOPs for laser system(s). Engineering controls include access control measures such as lockable doors, barriers, defeatable interlocks, and curtains to prevent laser radiation from leaving the restricted location.

Example: A research laboratory containing Class 3B and/or Class 4 lasers.

- c) Controlled location: Access, occupancy, and activities of people within are subject to strict control and supervision. By inference, controlled locations are restricted locations with laser radiation hazards at Class 4 with additional control measures specified by the laser operator, the LSO, and the employer management.

Example: A R&D area with positive access control and video surveillance.

- d) Exclusion location: Occupancy by people is possible, but is denied by the LSO during the operation of the laser system.

Example: A free electron laser machine room or beam path.

- e) Inaccessible location: Occupancy is not possible due to its dimensions.

Example: An enclosed beam path on an optical table.

An evaluation at each location should consider the probability of personnel exposure to hazardous laser radiation and each may be influenced by whether the laser is used indoors or outdoors. If exposure of unprotected personnel from the primary beam or from specular reflections of the beam is possible, then the LSO shall determine the irradiance or radiant exposure for the primary beam, or specular reflection of the beam as an extended source, at the location(s) of possible exposure (see Appendix B in ANSI Z136.1).

3.5 Personnel.

The LSO must consider the people who may be in the vicinity of the laser and its emitted beams, and whether or not to adopt additional control measures.

4. Control Measures

4.1 General Considerations.

Control measures shall be devised to reduce the possibility of exposure of the eye and skin to hazardous levels of laser radiation and other hazards associated with lasers and laser systems during operation, service and maintenance. The LSO shall have the authority to monitor and enforce the control of laser hazards, effect the knowledgeable evaluation and control of laser hazards, and conduct surveillance of the appropriate control measures. The LSO may, at times, delegate specific responsibilities to an authorized person. Authorized persons are those with knowledge of the hazards, including non-beam hazards, associated with the experiments of concern. The authorized person should not have a conflict of interest in the operation of the experiment.

For all uses of lasers and laser systems in restricted or controlled areas, the minimum laser radiation required for the application should be used. Also, the beam height should be maintained at a level other than the normal position of the eye of a person in the standing or seated positions unless additional controls have been put into place to protect individuals at such locations (e.g., workstations).

Laser safety training programs shall be established and documented to ensure that the laser users have a thorough understanding of the scope of laser hazards enabling them to choose the most appropriate and/or required control measures.

Engineering controls (items incorporated into the laser or laser system or designed into the installation by the user) shall be given primary consideration in instituting a control measure program for limiting access to laser radiation. Enclosure of the laser equipment and the beam path, or remote viewing and operation are the preferred methods of control to isolate or minimize the hazard. If engineering controls are impractical or inadequate, administrative and procedural controls and PPE shall be used. The limits of any type of control measure (for example, failure modes of enclosures and eye protection, or the inability of some personnel to understand written warnings) shall be considered when developing a laser hazard control program.

Whenever appropriate and possible, Class 4 lasers or laser systems should be controlled and monitored at a position as distant as possible from the beam aperture or beam path of the laser or laser system.

Upon review and approval by the LSO, the engineering control measures specified in 4.2 and administrative controls specified in 4.3 for Class 3B and Class 4 lasers or laser systems, may be replaced by procedural, administrative, or other alternate controls. Accordingly, if alternate control measures are instituted, then those personnel directly affected by such measures shall be provided the appropriate laser safety and operational training.

4.1.1 Special Note on Engineering Controls. Note that this standard (Z136.8) recognizes that in a research setting both "certified" and "non-certified" lasers and laser systems and components, and systems developed prior to product registration are in common use. With training, user awareness, LSO approved control measures and LSO authorization, these non-certified devices can be used in a safe manner. An example would be a diode laser being aimed into an optical fiber on a breadboard. Therefore engineering controls listed in 4.2,

which might be required controls that are found in certified products, will be “preferred” but not required in home built or non-certified lasers, laser systems or components. Prior to sending a laser system for technology transfer or use by others offsite, an effort should be made to bring them into existing product safety code compliance.

4.1.1.1 Applicability of Control Measures. The purpose of control measures is to reduce the possibility of human exposure to hazardous laser radiation (see Section 3) and to non-beam hazards (see Section 7). In some cases, more than one control measure may be specified. In such cases, more than one control measure that accomplishes the same purpose shall not be required.

4.1.1.1.1 Operation, Maintenance, and Service. Important in the implementation of control measures is the distinction between the functions of *operation*, *maintenance*, and *service*. Lasers and laser systems are classified on the basis of the level of the laser radiation accessible during intended use (operation). Operation is outlined in the SOPs and includes all activities that occur in the research environment (e.g., alignment, data collection, and performance testing). Maintenance is a task specified in the maintenance instructions for assuring routine performance of the laser or laser system. This may include such frequently required tasks as cleaning and replenishment of expendables. Maintenance may or may not require beam access. Service functions are usually performed with far less frequency than maintenance functions and may require access to the laser beam by those performing the service. Service functions, which are delineated in the laser or laser system manufacturer’s service manuals, may include replacing or aligning the laser resonator mirrors, flashlamps, dye cells, flow tubes, etc., or repair of faulty components.

The control measures described in the following subparagraphs of this section shall apply when a laser or laser system is in operation. During periods of service or maintenance, control measures appropriate to the class of the embedded laser shall be implemented when the beam enclosures are removed and beam access is possible. The fact that beam access is possible during maintenance or service procedures will *not alter* the classification of the laser system; classification is based on beam access conditions during operation. Extra care should be taken to prevent exposure to beam and non-beam hazards that may be present during these procedures. Instructions for the safe operation of lasers and laser systems are provided by the manufacturer. Under some conditions, such instructions may not be sufficiently detailed for specific application due to special use conditions. In this case, the LSO shall be consulted to provide additional safety instructions.

4.1.1.2 Supervised Laser Operation (Class 3B and Class 4). Class 3B and Class 4 lasers and laser systems shall be operated under the direct supervision or control of an experienced, trained operator who shall maintain visual surveillance of conditions for safe use and terminate laser emission in the event of equipment malfunction or any other condition of unsafe use. The operator shall maintain visual access to the entire LCA during all conditions of operation, unless the use conditions exist that fulfill the requirements of 4.1.1.3 are applied.

4.1.1.3 Unattended Laser Operation (All Classes). Only Class 1 lasers or laser systems shall be used for unattended operation in unsupervised areas without the implementation of additional control measures as detailed below.

If a Class 1M, Class 2, Class 2M, or Class 3R laser or laser system is not operated at all times under the direct supervision or control of an experienced, trained operator, the laser or laser system shall be provided with a clearly visible area warning sign that includes the applicable information.

If a Class 3B or Class 4 laser or laser system is not operated at all times under the direct supervision or control of an experienced, trained operator, the laser radiation levels shall be limited by control measures such as beam traps, barriers, windows, or other means of area control so that unprotected spectators in the area shall not be exposed to levels that exceed the applicable MPEs in any space in the area that they may occupy.

The unattended use of open beam path Class 3B or Class 4 lasers or laser systems shall be permitted only when:

- a) The laser user or laser operator has implemented appropriate control measures that provide adequate protection. This may include enclosures, limiting open beam access points, securing access to the area (e.g., electronic lock), posting of sign(s) warning about unattended laser operation, posting the immediate open unattended zone, or;
- b) Laser safety training is provided and documented to those who may enter the LCA during times of unattended use.
- c) The control area should be under interlock access control, which will reduce laser exposure to at or below the MPE if an unauthorized person should gain entry; and
- d) The LSO has approved the operation.

All areas where unattended Class 3B or Class 4 lasers and laser systems operate shall be provided with standard laser safety area warning signs containing the "DANGER" signal word and appropriate instructions regarding the hazards of entry into the space when an operator is not present.

4.1.2 Laser System Modifications (All Classes). The LSO may reclassify, using the provisions and requirements of this standard, a given laser or laser system that has been modified. However, lasers and laser systems that have been altered may necessitate recertification, reclassification, and compliance reporting under the requirements of the Federal Laser Product Performance Standard (FLPPS) CFR 21-1040.10.

4.2 Engineering Controls.

Commercial laser products manufactured in compliance with the FLPPS will be certified by the manufacturer and will incorporate those engineering controls required by the FLPPS or IEC 60825-1. Homemade, original equipment manufacturer (OEM), non-certified and certified laser components and products and combinations are commonly in use in the research setting. Only certified lasers are required to meet FLPPS or IEC 60825-1 requirements. Products being developed and then sent for offsite evaluation and out of the control of the developer should meet as many FLPPS or IEC 60825-1 requirements as possible (considering safety and the expectation of further development).

The LSO shall affect any additional engineering control measures that are required as outlined in this section. The use of the additional controls outlined in this section shall be considered in order to reduce the potential for hazards associated with some applications of

lasers and laser systems. The engineering controls for a laser or laser system are as specified in 4.2.1 to 4.2.10.

4.2.1 Operating a Laser without Protective Housing (Class 3B and Class 4). In some circumstances, such as research, development, and testing during the manufacture or servicing of lasers, operation of lasers or laser systems without a protective housing may become necessary. In such cases the LSO shall affect a hazard analysis and ensure that control measures appropriate to the class of maximum accessible emission level to assure safe operation. These controls may include, but not be limited to:

- a) LCA
- b) Eye protection
- c) Appropriate barriers, shrouds, and beam stops
- d) Administrative and procedural controls
- e) Education and training

4.2.2 Interlocks on Removable Protective Housings (All Classes with Embedded Class 3B or Class 4 Lasers). Commercial certified laser products with protective housings that enclose Class 3B or Class 4 lasers or laser systems shall be provided with an interlock system that is activated when the protective housing is opened or removed during operation and maintenance. The interlock or interlock system shall be designed to prevent access to laser radiation above the applicable MPE. The interlock may, for example, be electrically or mechanically interfaced to a shutter that interrupts the beam when the protective housing is opened or removed.

Fail-safe interlocks shall be provided for any portion of the protective housing that by design can be removed or displaced during operation and maintenance, and thereby allowing access to Class 3B or Class 4 laser radiation. One method to fulfill the fail-safe requirement is the use of redundant electrical series connected interlocks. Another alternative is requiring a tool for removing the housing or covering; an appropriate warning label shall be included on the panel/covering.

The protective housing interlock shall not be defeated or overridden during operation unless the provisions of 4.2.1 have been fully implemented.

Adjustments or procedures during service on lasers or laser systems containing interlocks shall not cause the interlocks to be inoperative when the equipment is restored to its operational condition.

4.2.3 Service Access Panels (All Classes). Portions of the protective housing that are only intended to be removed from any laser or laser system by service personnel for a specific research task, which then permit direct access to laser radiation associated with a Class 3B or Class 4 laser or laser system, shall either:

- a) Be interlocked (fail-safe interlock not required), or
- b) Require a tool for removal and shall have an appropriate warning label (see 4.6) on the panel.

If the interlock can be bypassed or defeated, a warning label with the appropriate indications shall be located on the protective housing near the interlock. The label shall include language appropriate to the laser hazard. The interlock design shall not permit the service access panel to be replaced with the interlock remaining bypassed or defeated.

4.2.4 Master Switch (Class 3B and Class 4). Commercial Class 3B and Class 4 lasers or laser systems should be provided with a master switch by the manufacturer in compliance with CDRH requirements. The master-switch effects beam termination and/or system shutoff and may be operated by a key, or by a coded access (such as a computer code). Class 3B and Class 4 lasers or laser systems developed in a R&D laboratory should be designed to incorporate similar means of safe activation and deactivation.

As an operational safety feature, the master switch can be designed to allow system activation using a momentary switch action (or alternative) that initiates system operation with the option that the key (or alternative) can be removed after operation commences. In this mode, if the system ceases to operate, the key switch (or alternative) must again be used to restart the laser or laser system. Operational control systems for multiple laser installations can be designed to include a single master switch to effect beam termination, shuttering, attenuation, or shutoff as appropriate for the specific laser operation.

The authority for access to the master switch shall be vested in the appropriate supervisory personnel to prevent unauthorized use of the laser or laser system. During periods of prolonged non-use (e.g., laser storage), the master switch should be left in a disabled condition (key removed or equivalent).

All energy sources associated with Class 3B and Class 4 lasers or laser systems should be designed to permit lockout/tagout procedures required by the Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor.

4.2.5 Viewing Windows, Display Screens, and Collecting Optics. In order to adequately address additional protection requirements, it is sometimes necessary to utilize various protective devices such as viewing windows, display screens, and laser barriers as defined in Section 2.

4.2.5.1 Viewing Windows and Diffuse Display Screens (All Classes). All viewing windows and diffuse (reflective or transmitted) display screens included as an integral part of a laser or laser system shall incorporate a suitable means (such as interlocks, filters, attenuators) to maintain the laser radiation at the viewing position at or below the applicable MPE as determined by the LSO. In cases where this is not possible remote viewing shall be utilized.

4.2.5.2 Flammability and decomposition products of the material. The flammability and decomposition products are important factors that must be considered in selecting window material and display screen material. Material used for viewing windows and diffuse display screens should not support combustion or release LGAC above the current occupational limits following exposure to laser radiation unless the proper safeguards are in place to ensure personnel safety (see Section 7).

4.2.5.3 Collecting Optics (All Classes). All collecting optics (e.g., lenses, telescopes, microscopes, endoscopes and eye-loupes) that integrate the use of a laser or laser system shall incorporate suitable means (such as interlocks, filters, attenuators, warning labels) to

limit the laser radiation transmitted through the collecting optics to levels at or below the appropriate MPE, as determined by the LSO. Collecting optics filter housings shall be labeled with appropriate user information or warning label.

NOTE— Normal or prescription eyewear is not considered collecting optics.

4.2.6 Beam Paths (Class 3B or Class 4). Control of the laser beam path shall be accomplished as described in the following:

4.2.6.1 Open Beam Path (Class 3B or Class 4). In applications of Class 3B and Class 4 lasers or laser systems where a beam path is unenclosed, a laser hazard evaluation shall be effected by the LSO. In some cases, the total hazard assessment may be dependent upon the nature of the environment, the geometry of the application, or the spatial limitations of other hazards associated with the laser use. This may include, for example, localized fume or radiant exposure hazards produced during laser material processing or surgery, robotic working envelopes, location of walls, barriers, or other equipment in the laser environment (see Section 7).

Frequently, the hazard analysis will define an extremely limited NHZ and procedural controls can provide adequate protection. Class 1 conditions shall be considered as fulfilled in two cases: 1) for those limited open beam path lasers or laser systems where analysis, including measurements when necessary, confirms that the accessible levels during operation are at or below applicable MPEs, and 2) where limited open beam paths are such that human access or the placement of a tool as part of normal operation is restricted.

4.2.6.2 Enclosed Beam Path (All Classes). In applications of lasers or laser systems where the entire beam path is enclosed, preventing human access to levels of laser radiation above Class 1 MPE (e.g., fiber optic or beam tubes), no further controls are required.

When the protective housing requirements are temporarily relaxed, such as during maintenance or service, the LSO shall effect the appropriate controls. These may include a temporary LCA and administrative and procedural controls.

Protective housings that are of sufficient size to allow personnel within the enclosure (walk-in protective housings) should either be interlocked, or have an alternate set of controls approved by the LSO.

4.2.7 Laser Area Warning Signs and Activation Warnings (Class 3B and Class 4).

Class 3B or Class 4 Laser Area: An area that contains a Class 3B or Class 4 laser or laser system shall be posted with the appropriate sign, except when exclusion applies.

WARNING Unattended Laser in Operation (Class 3B and Class 4): The exterior boundary of a non-interlocked laser use area that contains unattended open beams shall have an area warning sign posted indicating unattended laser in operation.

Temporary Laser Controlled Area (Class 3B and Class 4): The exterior boundary of a temporary LCA that contains a Class 3B or Class 4 laser or laser system shall be posted with a NOTICE sign. This NOTICE sign should also be posted during laser maintenance or service procedures.

4.2.7.1 Warning Signs for Non-Beam Hazards. Warning signs, as specified in ANSI Z535.2³ (see Multiple Hazard Labeling Requirements) and/or other standards applicable to the specific hazard(s), shall be posted when non-beam hazards as detailed in Section 7 are possible (e.g., LGACs, electrical, compressed gases). These can most often be found in the institution's chemical hygiene or hazard communication plan.

4.2.7.2 Activation Warning Systems (Class 3B and Class 4). An activation warning system should be used with Class 3B and Class 4 lasers and laser systems during activation.

For single pulse lasers or laser systems, an audible system may commence operation when the laser power supply is charged for operation, for example, during the charging of capacitor banks.

Distinctive and clearly identifiable sounds that arise from auxiliary equipment (such as a vacuum pump or fan) and are uniquely associated with the emission of laser energy are also acceptable as audible warnings. The most common use of an audible warning device is in laser operations associated with a radiation hazard, such as part of a sweep process of a Free Electron Laser (FEL) or optical accelerator.

Visible warning devices may be exterior to the LCA and exterior to the NHZ. A common example is a single red light or lighted laser warning sign that flashes when the laser is operating. Internal warning lights shall be visible through laser protective eyewear and also viewable within the NHZ. The light can be electrically interfaced and controlled by the laser power supply so that the light is on and flashing only when the laser is operating. The use of an interior laser warning light should be evaluated by the LSO. The sign must be readable while wearing laser protective eyewear and located in sufficient locations to be seen by all affected areas within the NHZ.

Another possible configuration can be a warning light assembly that may be interfaced to the laser controller to indicate conditions of enabled laser (high voltage on), laser on (beam on), and area clear (no high voltage or beam on). Note that only a green light shall be used to indicate a safe condition. In this case, the green light will indicate when the laser is not operational (high voltage off) *and* by an additional yellow light when the laser is powered up (high voltage applied, but no laser emission) *and* by an additional (flashing optional) red light that activates when the laser is operating. A flashing signal to indicate when the beam is on is superior to a constant on light. LED lights have a longer lifetime than standard lamps. Owing to LED's longer MTBF (mean time between failures) and reduced operating expense, their use should be instituted in lieu of standard incandescent lamp illumination wherever practical.

NOTE—The LSO shall consider alternative control measures for the hearing or visually impaired.

4.2.8 Indoor Laser Controlled Area (Class 3B and Class 4). A laser hazard analysis shall be affected by the LSO. If the analysis determines that the classification associated with the maximum level of accessible radiation is Class 3B or Class 4, an LCA shall be established and adequate control measures instituted.

³ ANSI Z535.2, American National Standard for Environmental and Facility Safety Signs.

NOTE—The requirements for non-enclosed lasers or laser systems involving the general public are detailed in ANSI Z136.1.

4.2.8.1 Indoor Laser Controlled Area (Class 3B). The LSO shall consider the use pattern (e.g., restricted, controlled location) in implementing these control measures. The Class 3B LCA shall:

- a) Be controlled to permit lasers and laser systems to be operated only by personnel who have been trained in laser safety and in the operation of the laser or laser system
- b) Be posted with the appropriate area warning sign(s), except if exclusions apply. An appropriate warning sign shall be posted at the entryway(s) and, if deemed necessary by the LSO, should be posted within the LCA
- c) Be operated in a manner such that the path is well defined
- d) Be well defined and controlled if the laser beam must extend outdoors and projects into a controlled airspace, particularly under adverse atmospheric conditions, e.g., rain, fog and snow (see Section 4.3.11.1 or 4.3.11.2 of ANSI Z136.1-2007 and ANSI Z136.6)

In addition to the above, a Class 3B LCA should:

- a) Be under the direct supervision of an individual knowledgeable in laser safety
- b) Be located so that access to the area by spectators is limited and requires approval
- c) Have any potentially hazardous beam terminated in a beamstop of an appropriate material
- d) Have only diffusely reflecting materials in or near the beam path, where feasible
- e) Provide personnel within the LCA with the appropriate eye protection
- f) Have the laser secured such that the exposed beam path is above or below eye level of a person in any standing or seated position, unless control measures have been put in place for personnel safety (except as required for medical use)
- g) Have all windows, doorways and open portals from an indoor facility either covered or restricted in such a manner as to reduce the transmitted laser radiation to levels at or below the applicable ocular MPE, if applicable
- h) Have restrictions in place to prevent unauthorized use

4.2.8.2 Indoor Laser Controlled Area (Class 4). All Class 4 area or entryway safety controls shall be designed to allow both rapid egress by laser personnel at all times and admittance to the laser controlled area under emergency conditions.

All personnel who require entry into a LCA shall be appropriately trained, provided with appropriate PPE, and shall follow all applicable administrative and procedural controls.

4.2.8.2.1 Emergency Conditions. The LSO shall evaluate whether reduction in laser output power or a complete operational shutdown is required in cases of emergency, along with the manner to obtain that condition. One approach is to use a clearly marked “Emergency Stop” mechanism or other marked device for this intended purpose (remote controlled connector or

circuit breaker) available for deactivating the laser or reducing the output to levels at or below the applicable MPE.

4.2.8.2.2 Entryway Controls. The Class 4 LCA shall be designed to fulfill the items of 4.2.8.1, and in addition shall incorporate one of the following alternatives:

a) Non-defeatable (non-override) Area or Entryway Safety Controls

Non-defeatable safety latches, entryway or area interlocks (e.g., electrical switches, pressure sensitive floor mats, infrared, or sonic detectors) shall be used to deactivate the laser or reduce the output to levels at or below the applicable MPE in the event of unexpected entry into the LCA.

b) Defeatable Area or Entryway Safety Controls

Defeatable safety latches, entryway, or area interlocks shall be used if non-defeatable area/entryway safety controls limit the intended use of the laser or laser system. For example, during normal usage requiring operation without interruption (e.g., long term testing and warm up periods), if it is clearly evident that there is no laser radiation hazard at the point of entry, override of the safety controls shall be permitted to allow access to authorized personnel provided that they have been trained and provided with PPE.

c) Procedural Area or Entryway Safety Controls

Where safety latches or interlocks are impractical or inappropriate (e.g., limited open beam paths, fiber operations, and enclosed beam paths), the following shall apply:

1. All authorized personnel shall be trained and PPE shall be provided upon entry.
2. A means shall be used to block, screen, or attenuate the laser radiation at the entryway (e.g., door, blocking barrier, screen, or curtains). The level of laser radiation exterior to these devices shall not exceed the applicable MPE, nor shall personnel experience any exposure above the MPE immediately upon entry.
3. At the entryway there shall be an activation warning system indicating that the laser is energized and operating at Class 4 levels.

4.2.9 Outdoor Control Measures (All Classes). A laser hazard analysis shall be affected by the LSO. If the analysis determines that the classification associated with the maximum level of accessible radiation is Class 3B or Class 4, an LCA shall be established and adequate control measures instituted.

NOTE—The requirements for non-enclosed lasers or laser systems involving the general public are detailed in ANSI Z136.1.

4.2.9.1 General. All Class 3B and Class 4 lasers or laser systems used outdoors shall meet the following requirements:

- a) The LSO shall affect an analysis to establish the NHZ if not provided as part of the documentation furnished by the manufacturer.

- b) If visible lasers are used at night, the LSO shall effect an analysis to determine if the laser beams will visually interfere with critical tasks. Visual interference occurs at levels far below the MPE. For operation of visible lasers at night near airports, refer to Federal Aviation Administration (FAA) Order 7400.2 and ANSI Z136.6.
- c) The NHZ shall be clearly posted with laser warning signs and demarcated and identified as the laser hazard area.
- d) All personnel authorized to enter the NHZ shall be appropriately trained.
- e) Only personnel who have been authorized shall operate a laser or laser system.
- f) Appropriate combinations of physical barriers, screening, and PPE shall be provided and used by those personnel authorized within the NHZ (see 4.5).
- g) Appropriate administrative controls shall be used if personnel are permitted within the NHZ.
- h) Directing the laser beam toward automobiles, aircraft, or other manned structures or vehicles shall be prohibited unless adequate training and PPE is provided and used by all affected personnel or as authorized by the LSO and permitted by FAA Order 7400.2.
- i) The exposed laser beam path shall not be maintained at or near personnel eye level without specific authorization of the LSO.
- j) The beam path shall be confined and terminated wherever possible.
- k) When the laser is not being used, it shall be disabled in a manner that prevents unauthorized use.
- l) The operation of Class 4 lasers or laser systems during rain, snowfall, fog, or dusty atmosphere may produce hazardous scattering near the beam. In such conditions, the LSO shall evaluate the need for and specify the use of PPE.

4.2.9.2 Use of Lasers in Navigable Airspace (All Classes). The FAA is responsible for regulating the efficient utilization of navigable airspace to ensure the safety of aircraft and the protection of people and property on the ground. Laser experiments or programs that will involve the use of lasers or laser systems in navigable airspace should be coordinated with the FAA (Washington, DC 20590, or any FAA regional office) and U.S. Space Command in the planning stages to ensure proper control of any attendant hazard to airborne personnel or equipment. Also refer to FAA Order 7400.2 and ANSI Z136.6. Laser light show demonstrations that use Class 3B or Class 4 laser systems to create visible open beams shall coordinate with the Food and Drug Administration (FDA) prior to use.

4.2.10 Temporary Laser Controlled Area-TLCA (All Classes)/Temporary Laser Work Area-TLWA. In those conditions where removal of panels or protective housings, overriding protective housing interlocks, or entry into the NHZ becomes necessary (e.g., service, troubleshooting, alignment, testing, limited duration experimental procedures) and the accessible laser radiation exceeds the applicable MPE, a TLCA shall be established for the laser or laser system.

Such an area, that by its nature will not have the built-in protective features as defined for an LCA, shall provide all safety requirements for all personnel both within and outside the area.

A TLCA can be useful for new system acceptance testing, establishing laser controls and short term use of Class 3B and Class 4 laser systems.

A Notice sign shall be posted outside the TLCA to warn of the potential hazard (see figure 1d).

4.3 Administrative and Procedural Controls.

Administrative and procedural controls are methods or instructions that specify rules, work practices, or both, which implement or supplement engineering controls and which may specify the use of PPE. Unless otherwise specified, administrative and procedural controls shall apply only to Class 3B and Class 4 lasers or laser systems.

4.3.1 Standard Operating Procedures (Class 3B and Class 4). The LSO shall require and approve written standard operating, maintenance and service procedures (SOPs) for Class 3B and Class 4 lasers or laser systems. (Continuous wave visible lasers at or below 15 mW are exempt from this requirement). These written SOPs should be maintained with the laser equipment for reference by the operator, maintenance and service personnel.

4.3.2 Education and Training (All Classes except Class 1). Education and training shall be provided for operators, maintenance and service personnel for Class 3B and Class 4 lasers or laser systems. Education and training should be provided for operators, maintenance and service personnel for Class 1M, and Class 2M lasers or laser systems and Class 1 lasers or laser systems containing embedded Class 3B or Class 4 lasers. The level of training shall be commensurate with the level of potential hazard.

4.3.3 Authorized Personnel (Class 3B and Class 4 and Embedded Class 3B and Class 4 Lasers). Class 3B and Class 4 lasers or laser systems shall be operated, maintained, or serviced only by authorized personnel. The definition/elements of authorized personnel is to be determined by the supervising organizations (e.g., fundamental laser safety training, on-the-job training). Lasers or laser systems with enclosed Class 3B or Class 4 lasers shall be maintained or serviced only by authorized personnel if such procedures would permit access to levels that exceed the Class 3R AEL.

4.3.4 Alignment and Other Open Beam Procedures (All Classes except Class 1). Laser incident reports have repeatedly shown that an ocular hazard may exist during beam alignment procedures. The use of lower power (Class 1, Class 2 or Class 3R) visible lasers for path simulation of higher power lasers is recommended for alignment of higher power Class 3B and Class 4 visible or invisible lasers and laser systems.

Alignment of Class 3B and Class 4 laser optical systems (e.g., mirrors, lenses, and beam deflectors) shall be performed in such a manner that the primary beam, or a specular or diffuse reflection of the beam, does not expose the eye or skin to a level above the applicable MPE.

There are many instances, such as during service, troubleshooting, testing and experimenting, when a temporary beam attenuator placed over the beam aperture can reduce the level of accessible laser radiation to levels at or below the applicable MPE.

Written SOPs outlining alignment operations shall be approved by the LSO for Class 3B and Class 4 lasers or laser systems. SOPs shall also be applicable for all classes of lasers or laser

systems that contain embedded Class 3B or Class 4 lasers under conditions that would allow access during alignment procedures.

4.3.5 Alignment and Other Open Beam Procedures for Class 3B and Class 4 Lasers.

Other open beam procedures may include but are not limited to setting up, testing, use of measurement equipment within the laser beam to measure power/energy or other beam parameters (e.g., shape, spatial properties, size, divergence), and experimental laser runs. Alignments should be done only by those who have received laser safety training or appropriate on the job training and are aware of any non-beam hazards that may arise (Section 7). In addition, the following actions should be taken:

- a) Exclude unnecessary personnel from the laser area during alignment.
- b) Whenever possible, use low-power visible lasers for path simulation of higher-power visible or invisible lasers.
- c) Wear protective eyewear and clothing as determined in consultation with the LSO
 1. Laser alignment eyewear, with visible lasers
 2. Lab coat or long sleeve shirts, with UV lasers
- d) When aligning invisible (and in some cases visible) laser beams, use beam display devices such as image converter viewers or phosphor cards to locate beams.
- e) Whenever possible the use of remote viewing devices (CCD, web cams) and automated devices (motorized mounts) should be considered.
- f) Perform alignment tasks that use high-power lasers at the lowest possible power level.
- g) Use a shutter or beam block to block high-power beams at their source except when actually needed during the alignment process.
- h) Use a laser-rated beam block to terminate high-power beams down range of the optics being aligned.
- i) Use beam blocks and/or laser protective barriers in conditions where alignment beams could stray into areas with uninvolved personnel.
- j) Place beam blocks behind optics (e.g., turning mirrors) to terminate beams that might miss mirrors during alignment.
- k) Locate and block all stray reflections before proceeding to the next optical component or section.
- l) Be sure all beams and reflections are properly terminated before high-power operation.
- m) Post appropriate area warning signs during alignment procedures where lasers are normally Class I (enclosed).
- n) Replace any enclosures or beam blocks removed as part of the alignment process.

4.3.6 Service Personnel (All Classes). Personnel who require access to Class 3B and Class 4 lasers or laser systems enclosed within a protective housing or protected area enclosure shall comply with the appropriate control measures of the enclosed or embedded laser or laser

system. The LSO shall confirm that service personnel have the education and safety training commensurate with the class of the laser or laser system contained within the protective housing. This confirmation may be in the form of a request for a safety plan from the vendor or manufacturer.

4.4 Special Considerations.

4.4.1 Visitors & Spectators (Class 3B or Class 4). Visitors and spectators shall be permitted within a laser controlled area that contains a Class 3B or Class 4 laser or laser system only when all of the following conditions have been met:

- a) Appropriate approval from the Principal Investigator (or the written designate) has been obtained
- b) The degree of hazard and avoidance procedure has been explained
- c) The NHZ has been explained
- d) Appropriate PPE such as laser eyewear and barriers are in use
- e) The direct supervision or control of an experienced, trained operator who maintains visual surveillance of conditions for safe use
- f) The LSO has approved the SOP for visitor/spectator access that outlines a) – e) and any site specific requirements

4.4.2 Laser User Facilities (Class 3B and Class 4). User facilities can range from large facilities such as free electron laser centers, synchrotron, and accelerator facilities to small ultra short pulse laser and mixed user facilities. Class 3B and Class 4 laser systems at user facilities can present unique challenges to the LSO based on the structure and policies at the facility, as well as the user community. The LSO should take these factors into consideration when developing and approving policies and SOPs for users at these facilities.

The LSO shall be notified of any new or modified beam paths that may impact safety so that a new hazard analysis can be performed (Section 3). If at any time the supervisor (lead scientist) of the facility is unsure of possible hazards associated with a user's experiment, the LSO and other appropriate safety personnel should be consulted. In this case an SOP for each user/experiment shall be generated and available for reference by the laser user(s) and the LSO.

4.4.2.1 Training at User Facilities. Due to the nature of user facilities users may spend only a short length of time at the facility. Users may also not be familiar with local safety codes; therefore they should receive a safety orientation including requirements to operate lasers sweep procedures, limitations on their activities in addition to general safety, such as evacuation routes. Visiting users under constant supervision of an authorized laser user may be exempt from required laser safety training if that is the facility policy. However, all laser users having access to open beam laser radiation (regardless of length of visiting duration) shall have met all the requirements of an authorized user.

4.4.3 Laser Optical Fiber Use (All Classes) Laser systems where the radiation transmitted through an optical fiber shall be considered enclosed with the optical cable forming part of the enclosure. If disconnection of a connector results in accessible radiation reduced to below the applicable MPE by fiber loss or engineering controls, then connection or disconnection

may take place in an uncontrolled area and no other control measures are required. When the system provides access to laser radiation above the applicable MPE via a connector, the conditions in 4.4.3.1 or 4.4.3.2 shall apply.

NOTE—The use of NHZ and nominal ocular hazard distance (NOHD) calculations can be taken into consideration in determining if an LCA should be established during connection or disconnection of fibers.

4.4.3.1 Connection or disconnection during operation shall take place in an appropriate LCA, which may be a small or large area.

4.4.3.2 Optical fibers or optical fiber cables attached to Class 3B and Class 4 lasers or laser systems should not be disconnected prior to termination of transmission of the beam into the fiber. In cases when power termination is not possible and laser radiation above the applicable MPE can be made accessible by disconnection of a connector, the connector shall bear a label or tag bearing the words “Hazardous Laser Radiation when Disconnected” (or a similar message). When the connection or disconnection is only possible with the use of a specific tool, this is equivalent to an interlocked system.

4.4.3.3 Fiber Optic Safety Guidelines

- a) Always work with fiber optic cables as if they were active/live.
- b) Do not look straight into the end of a fiber.
- c) The NHZ from a fiber with a micro lens is similar to that of a collimated beam.
- d) Make sure fibers are terminated into an instrument (power meter) or suitable end caps.
- e) Because of glass particle hazards, do not touch your eyes while performing fiber connectorizing or splicing work. Do not touch contact lenses until you are sure your hands are clean. Always wash your hands before touching your eyes.
- f) Do not eat in the same area you are working. Always wash your hands before eating. Particles of glass from an optical fiber are the same as splinters and can cause internal hemorrhaging.
- g) The fiber strand ends are extremely sharp and can easily penetrate your skin or eye. When broken off they are very hard to find and remove.
- h) Do not smoke in work areas.
- i) Properly label all fibers in conduit and jacketed fiber (bare fibers may not accept labeling).

4.4.4 Laser Robotic (Automated) Installations (Class 3B and Class 4). In some applications (e.g., industrial) Class 3B or Class 4 lasers and laser systems are used in conjunction with robots or automated systems. In these situations, the robot working envelope should also include the NHZ associated with the laser. Automated laser installations in research settings should be of limited open beam path and have controls to restrict human access. The user needs to be aware that mechanical or other non-beam hazards may be the greater risk to users. In all cases where the beam is focused by a lens associated with the robotic device, appropriate laser-robotic safeguards can be assured if:

- a) The design and/or control measures in combination provide for a positive beam termination during operation
- b) The beam geometry is limited to only the necessary work task
- c) All workers are located at a distance greater than or equal to the lens-on-laser NHZ value for the laser-robotic system.

In many instances, including those created by hardware failure and software errors, the laser beam from robotic delivery systems can be incident on the target surface at angles that could lead to complex scattering geometries that require extensive evaluation. Measurements are often required to confirm the NHZ boundaries.

4.4.4.1 Laser Robotics with Inaccessible Beam Paths. A robotic (automated) installation can be set up so an open beam area is inaccessible to the user at an established control station. This can be from barriers, the foot print of the system or the limitations of the beam path. In such cases the Class 3B or Class 4 beam will be considered to meet the Class 1 system requirements.

4.4.5 Export Controls. The LSO should ensure that the institution is aware of existing export control regulations. These are federal laws that prohibit the unlicensed export of certain commodities or information for reasons of national security or protections of trade. A laser of any classification may be subject to these regulations due to the laser's type or application. These commodities or information include any oral, written, electronic or visual disclosure, shipment, transfer or transmission of commodities, technology, information, technical data, assistance or software codes to:

- a) Anyone outside the U.S., including a U.S. citizen
- b) Any non-U.S. individual regardless of location
- c) Any foreign embassy or affiliate

Many lasers do not require government licenses. However, licenses are required for exports that the U.S. government considers "license controlled" under:

- a) The Department of Commerce's Export Administration Regulations (EAR – 15 CFR 730-774), which covers the export of goods and services identified on the Commodity Control List
- b) The Department of State's International Traffic In Arms Regulations (ITAR – 22 CFR 120-130), also known as the U.S. Munitions List, which covers defense-related items and services
- c) The Treasury Department's Office of Foreign Assets Control (OFAC – 31 CFR 500-599), which covers control of certain products to certain countries

4.5 Personal Protective Equipment.

4.5.1 General. Enclosure of the laser equipment or beam path is the preferred method of control, since the enclosure will isolate or minimize the hazard.

When other control measures do not provide adequate means to prevent access to direct or reflected beams at levels above the MPL, it may be necessary to use PPE such as goggles or

spectacles, skin protection such as clothing or gloves, as well as equipment such as barriers and filter windows.

It should be noted that PPE should not be used as the only control measure with Class 4 lasers or laser systems; the protective equipment may not adequately reduce or eliminate the hazard, and may be damaged by the incident laser radiation.

4.5.2 Protective Eyewear (Class 3B and Class 4).

4.5.2.1 Eye Protection (Class 3B and Class 4). Eye protection devices that are specifically designed for protection against radiation from Class 3B lasers or laser systems should be administratively required within the NHZ and their use enforced when engineering or other procedural and administrative controls are inadequate to eliminate potential exposure in excess of the applicable MPE.

Eye protection devices that are specifically designed for protection against radiation from Class 4 lasers or laser systems shall be administratively required and their use enforced when engineering or other procedural and administrative controls are inadequate to eliminate potential exposure in excess of the applicable MPE.

Laser protective eyewear is usually not required for Class 1M, 2, 2M or Class 3R lasers or laser systems except in conditions where intentional long-term (> 0.25 s) direct viewing is required.

Laser protective eyewear shall be specifically selected to withstand either direct or diffusely scattered beams depending upon the anticipated circumstances of exposure. In this case, the protective filter shall exhibit a damage threshold for a specified exposure duration, typically 10 s. The eyewear shall be used in a manner such that the damage threshold is not exceeded in the “worst case” exposure scenario. Important in the selection of laser protective eyewear is the factor of flammability (see ANSI Z87.1⁴).

Studies have indicated that some laser eye protective filters (absorptive polycarbonate and glass, dielectric coated interference, and/or hybrid filters) often exhibit non-linear effects such as saturable absorption when exposed to ultrashort (e.g., femtosecond) pulse durations. Laser users should request test data from the laser eyewear manufacturer (see ANSI Z136.7⁵, which specifies these same flammability and damage thresholds). Protection may vary within the same pair of protective eyewear based on the eyewear coating and incident angle of the laser beam. The user should understand any limitations of the selected laser protective eyewear.

4.5.2.2 UV Laser Protection. Due to the potential for significant photochemical bioeffects and the high level of scattering of UV radiation by air molecules, particular care shall be taken when using UV lasers or laser systems. In addition to other laser controls, which apply to all laser systems, exposure to UV radiation shall be minimized by using beam shields and clothing that attenuate the radiation to levels below the applicable MPE for the specific UV wavelengths.

⁴ ANSI Z87.1, American National Standard for Occupational and Educational Personal Eye and Face Protection Devices.

⁵ ANSI Z136.7, American National Standard for Testing and Labeling of Laser Protective Equipment

Special attention shall be given to the possibility of producing undesirable reactions in the presence of UV radiation: for example, formation of skin sensitizing agents, ozone and LGACs. PPE shall be used when working with open beam Class 3B and Class 4 UV lasers. This shall include both eye and skin protection.

4.5.2.3 Eyewear for Protection Against Other Agents. Physical and chemical hazards to the eye can be reduced by the use of face shields, goggles, and similar protective devices (see ANSI Z87.1).

4.5.2.4 Factors in Selecting Appropriate Eyewear. The following factors shall be considered in selecting the appropriate laser protective eyewear:

- a) Laser power and/or pulse energy for which protection (worst case) is required
- b) Wavelength(s) of laser output
- c) Exposure time criteria
- d) Maximum permissible exposure (MPE)
- e) Optical density requirement of eyewear filters at laser output wavelength(s)
- f) Potential for multi-wavelength operation
- g) Radiant exposure or irradiance levels
- h) Potential degradation and/or optical density (OD) reduction from ultra-short pulses (duration less than a nanosecond)
- i) Angular dependence of protection afforded
- j) Visible light transmission requirement and assessment of the effect on the ability to perform tasks while wearing the eyewear
- k) Need for side-shield protection and maximum peripheral vision requirement; side shields shall be considered and should be incorporated where appropriate
- l) Need for prescription glasses
- m) Comfort and fit
- n) Degradation of OD of filter media over time
- o) Strength of materials (resistance to mechanical trauma and shock) (see ANSI Z87.1 for appropriate criteria)
- p) Capability of the front surface to produce a hazardous specular reflection outside the NHZ
- q) Requirement for anti-fogging design or coatings

4.5.2.5 Optical Density.

4.5.2.5.1 Specification of Optical Density (OD). The OD (attenuation) of laser protective eyewear at a specific wavelength (D_s) shall be specified. Many lasers radiate at more than one wavelength; thus eyewear designed to have an adequate OD for a particular wavelength could have a completely inadequate OD at another wavelength radiated by the same laser. This problem may become particularly serious with lasers that are tunable over broad

wavelength bands. In such cases, alternative methods of eye protection, such as indirect viewing, may be more appropriate (e.g., image converters, closed circuit TV).

If the potential eye exposure level or value is given by H_p , the OD required of protective eyewear to reduce this exposure to the MPE is given by

$$OD = \log_{10} (H_p / \text{MPE}) = -\log_{10} \tau_\lambda$$

where H_p is expressed in the same unit as the appropriate MPE and τ_λ is the transmittance of the filter at the specific wavelength (see Section 8).

NOTE—When the laser beam diameter is smaller than the limiting aperture (D_f), the value of H_p is determined by averaging the beam energy over the limiting aperture (7 mm for the 400 to 1400 nm wavelength region). This is necessary since the MPE has been established (normalized) relative to the limiting aperture area. Use of the beam diameter (a) to evaluate H_p for cases where $a < D_f$ will result in excessively large OD requirements.

If the beam size is larger than the size of the protective eyewear, it should be noted that ODs greater than 3 or 4 (depending upon exposure time) could reduce eye exposure below the ocular MPE but leave the unprotected skin surrounding the eyewear exposed to values in excess of the skin MPE as specified in ANSI Z136.1. Note that the OD of the protective material shall be determined for all anticipated viewing angles and wavelengths.

4.5.2.5.2 Optical Density Time Basis Criteria. The duration of intended use of the laser or laser system shall be used as the time factor upon which the MPE computation is based when computing the OD of a filter material (see Tables 2 and 4). The following are recommendations that are applicable in determining the time factor criteria:

- a) **Aversion Response Criteria to Visible Lasers (400-700 nm) (Class 3B and Class 4).** When long-term intrabeam exposure to visible lasers is not intended, the applicable MPE used to establish the OD requirement for eye protection should be based on an exposure time of 0.25 s (see Section 8.1). This time factor is based upon the human aversion response time for a bright light stimulus. Thus, this becomes the “first line of defense” for unexpected exposure to some lasers (see ANSI Z136.1).
- b) **Near Infrared Criteria (Class 3B and Class 4).** When long-term exposure to point source, near infrared (700 to 1400 nm) lasers is not intended, the applicable MPE used to establish the OD requirement for eye protection should be based on a 10 s exposure. This represents a realistic “worst case” time period because natural eye motions dominate for periods longer than 10 s.
- c) **Diffuse Viewing Criteria (Class 3B and Class 4).** When viewing an extended source or the diffuse reflection of the beam from a Class 3B or Class 4 laser or laser system where intermediate viewing time is intended, e.g., during optical alignment procedures, the applicable MPE should be based on the maximum viewing time that may be required during any given 8 hour period.

When long-term exposure to visible (400-700 nm) CW lasers is not specifically intended, the applicable MPE used to establish the OD requirement for eye protection may be based on a 600 s exposure. This represents a typical “worst case” time period during tasks such as alignment and is applicable for most alignment procedures when viewing a diffusely reflecting target. In some situations where prolonged staring is

anticipated, such as during surgical laser usage, even longer times should be considered, based upon actual conditions of use.

Note that if the extended source criteria are not applicable due to a small beam size, then the exposure at the cornea from a diffuse reflector may be estimated using the inverse square law relationship, and the point source MPE criteria shall apply. In that case,

$$E = \rho \Phi \cos \theta_v / (\pi r_1^2)$$

where E is the irradiance produced at a distance r_1 (cm) from a diffuse surface when the surface is irradiated by a laser with output Φ (watts), and where ρ is the reflection coefficient of the surface, and θ_v is the viewing angle relative to the normal to the surface.

If the angular source size exceeds α_{\min} at the distance r_1 , the extended source criteria apply.

- d) **Daily Occupational Exposure Criteria (Class 3B and Class 4).** The time period of 30,000 s represents a full one-day (8-hour) occupational exposure and is determined from the approximate number of seconds in an 8 hour period.

The exposure duration is equal to the maximum time of anticipated direct exposure, which in a 24 hour period will not exceed 30,000 s except for UV wavelengths where additivity may occur (see Section 8.2.3.1 of ANSI Z136.1-2007).

When long-term exposure to any laser is possible, the applicable MPE used to establish the OD requirement for eye protection shall be based on a 30,000 s exposure.

4.5.2.5.3 Optical Density for Non-Laser Emissions. Eye protection shall be provided for the UV and blue-green spectral region (180 to 550 nm) for laser welding processes. On the basis of currently available data, a minimum OD of 2.0-3.0 (neutral density) or welding shade 6 (see ANSI Z87.1) is recommended for emission in the UV and blue-green spectral regions. The OD values given above would apply for the laser induced plasma, such as that associated with typical laser welding systems. Greater ODs are required for higher power laser welding systems.

The OD for plasma emission does not replace the OD requirements for laser emission.

4.5.2.6 Visible Luminous Transmission. The visible luminous transmission (VLT) of the protective filter that is needed to accomplish the task should be considered to allow adequate visibility without reducing the OD necessary for laser protection. The VLT of the protective filter shall be routinely provided, or be available upon request from the manufacturer. These requirements should be used to aid in the selection of appropriate eyewear/materials. The VLT shall be computed and available for the light- (photopic) and dark- (scotopic) adapted eye (see ANSI Z136.7).

An adequate OD at the laser wavelength of interest shall be weighed with the need for adequate visible transmission. The minimum adequate acceptable photopic and scotopic VLT is approximately 20% for most applications (see ANSI Z136.7-2008, Sections 3.1.3 and

3.1.4). At VLT levels less than 20%, other non-beam hazards may exist by virtue of diminished visual acuity; the most serious of which is electric shock (see Section 7).

NOTE—Sunglasses are typically 12 to 18% photopic luminous transmittance. Normally the minimum acceptable scotopic luminous transmittance is approximately 20% for unaided applications during reduced ambient illumination.

Additionally, various illuminant light sources may be utilized by laser eyewear protection (LEP) manufacturers in their respective calculations of VLT that may alter the stated VLT from one manufacturer to the next by as much as 10% in similar products. Therefore, the LSO may deem it appropriate to evaluate the VLT designations in light of these disparities and should contact the manufacturer where an apparent stated VLT irregularity may exist. Moreover, some LEP filters possess contrast enhancement properties that may augment a particular wavelength region(s) of visual interest, or neutral density filters that uniformly attenuate the visible spectrum to a given OD. As such, similar filters have advantageous transmission properties that are not directly affected by strict VLT evaluation alone.

4.5.2.7 Identification of Eyewear. All LEP shall be clearly labeled with the OD and wavelength for which protection is afforded. In addition to the manufacturer's OD and wavelength labeling information, the user may choose to use distinctive identification of LEP in multi-laser environments to aid users in the selection and use of approved eyewear.

NOTE—Commercial LEP may have a duplicate labeling compliant with European Norm (EN) 207 or 208 testing conditions where:

D stands for continuous wave

I stands for pulsed with pulse length $> 1 \mu\text{s}$ and $< 250 \text{ ms}$

R stands for pulsed with pulse length $> 1 \text{ ns}$ and $< 1 \mu\text{s}$

M stands for pulsed laser with pulse length $< 1 \text{ ns}$

L stands for scale number (close to OD)

EN207 and EN208 "L" ratings are presented for informational purposes only and are not applicable for either the evaluation or selection of non-European (CE) laser eye protection products. For guidance in the selection of laser eyewear products (see ANSI Z136.1 and ANSI Z136.7).

4.5.2.8 Cleaning and Inspection. Periodic cleaning and inspection shall be made of LEP to ensure the maintenance of satisfactory condition. The frequency of the safety inspection should be at least once per year, or as determined by the LSO. This shall include:

- a) Periodic cleaning of the eyewear. Care should be observed when cleaning lenses of LEP to avoid damage to the absorbing and/or reflecting surfaces. In some uses (e.g., surgery) eyewear may require cleaning (and sterilization) after each use. Consult eyewear manufacturers for instructions for proper cleaning methods.
- b) Inspection of the attenuation material for pitting, crazing, cracking, discoloration.
- c) Inspection of the frame for mechanical integrity.
- d) Inspection for light leaks and coating damage.

Eyewear in suspicious condition should be tested for acceptability or discarded.

4.5.2.9 Purchasing Information for Protective Eyewear. Purchasers of LEP should require that the following information accompanies each item:

- a) Wavelength(s) and corresponding OD for which protection is afforded;
- b) Pertinent data such as damage threshold for laser safety purposes; and
- c) Manufacturers' recommendations on shelf life, storage conditions, cleaning and use.

4.5.2.10 Alignment Eyewear. For alignment of visible beams, conditions may arise that require the user to see the beam through their protective eyewear (cases where remote viewing is not possible). In these situations the use of alignment eyewear can be approved by the LSO. Alignment eyewear is assigned an OD lower than that which will provide full protection from a direct accidental exposure. For continuous wave lasers the alignment OD shall reduce irradiance to a Class 2 to Class 3R level. For pulse lasers the alignment OD shall be no more than 1.4 less than the full protection OD.

4.5.2.10.1 Factors in Selecting Alignment Eyewear. Alignment eyewear by definition involves the use of visible laser light and requires the same attention and hazard analysis needed to adequately attenuate light from potential or accidental exposures to levels below MPEs by applying appropriate time base criteria. Ultimately the LSO shall approve the selection, use and appropriate OD values for all alignment tasks with the ultimate goal to adequately attenuate light to levels safely below MPEs for all potential or accidental ocular exposures.

The primary ocular hazard during alignment procedures is associated with improper use of the LEP product wherein the OD value fully attenuates the point source diffused (non-specular) beam such that alignment viewing is not possible. In such instances, LEP is typically removed, or not worn, for beam alignment capability and thereby commensurately increasing the potential for eye injury.

To assist in the process of selecting alignment eyewear, the LSO shall calculate OD values for both point source intrabeam and point source diffused (non-specular) viewing. If point source diffused OD values are employed by the LSO when selecting LEP, notification to the end-user shall indicate that the wearer of same is not protected against a point source intrabeam exposure as its MPE values will be exceeded. For LEP alignment viewing, the LSO also shall not recommend LEP product(s) that possesses an OD value less than the point source diffused (non-specular) OD requirement.

4.5.2.11 Limitations of Laser Eye Protection. Absorptive polycarbonate and glass filters and laminated or dielectric coated (reflective) filters used in the construction of laser protective eyewear all have physical damage thresholds that may be exceeded under certain conditions. As noted, the advent of ultrashort, higher peak power and higher pulse repetition rate laser systems presents conditions that may require additional testing information from the manufacturer when selecting eyewear for these lasers. See ANSI Z136.7 for further guidance.

4.5.2.11.1 Use with High-power Lasers. Engineering control measures shall be implemented with high-power, multi-kilowatt laser beams. If engineering control measures are impractical, administrative control measures may be used. LEP may be inadequate to protect the user from serious ocular exposure from such laser beams. Additionally, if the

multi-kilowatt laser beam does not strike the LEP, the skin of the face may receive a significant injury (e.g., third-degree burn and laceration from facial motion during exposure).

Most of the radiant energy absorbed by the filter is transformed into heat. If the radiant flux is quite high, as it would be for multi-kilowatt beams, the heat may fracture a glass lens or melt polycarbonate. If the radiant energy is concentrated in a small diameter spot, enhanced heat transfer may result in damage to the surrounding matrix material. The latter may occur for radiant power much less than a kilowatt.

It is possible (even likely for powerful lasers) that the filter material, glass or plastic, may be damaged in a time period that is shorter than the time base used to determine the MPE (see Table 2). This is particularly true as the radiant exposure increases. Guidance on typical laser-induced damage threshold (LIDT) levels may be found in ANSI Z136.7. For polycarbonate, these values are 10 J/cm^2 ($t < 10^{-3} \text{ s}$) and $300 t^{0.5} \text{ J/cm}^2$ ($t \geq 10^{-3} \text{ s}$), where t is the exposure duration. For glass, the values are 1 J/cm^2 ($t < 10^{-6} \text{ s}$) and $1000 t^{0.5} \text{ J/cm}^2$ ($t \geq 10^{-6} \text{ s}$).

Users of LEP shall be trained to understand potential early signs of damage. These may include, but are not limited to, smoke, flame, incandescence, and luminescence.

4.5.2.11.2 Saturable Absorption. Certain dyes used to absorb laser radiation may undergo saturable absorption (also called induced transmittance or transient photobleaching) where the ability to absorb radiant energy decreases with increasing radiant exposure or peak irradiance. When this occurs, the OD may decrease providing less protection to the user.

This has been reported for both absorptive glass and polycarbonate filters for certain pulsed lasers and is associated with high values of peak irradiance. Lasers evaluated were pulsed (Q-switched and ultrashort pulses) Ti-sapphire and Nd:YAG (1064 nm and 532 nm).

When applicable, as part of the pre-purchase review for LEP utilizing absorbing dyes (including hybrid filters), the LSO shall ensure that the potential for saturable absorption is evaluated (see ANSI Z136.7).

4.5.2.11.3 Angle of Exposure. Based on the composition of the laser LEP filter, the angle of exposure can have an affect on the effectiveness of the eyewear filter.

Dielectric coatings on LEP are designed to deliver the labeled OD within a set angle of acceptance. Laser radiation incident upon the eyewear outside that angle will yield a diminished OD. The obliqueness of the angle may or may not limit the laser radiation entering the pupil.

4.5.3 Facility Window Protection (Class 3B and Class 4). Facility windows (exterior or interior) that are located within the NHZ of a Class 3B or Class 4 laser or laser system shall be provided with an appropriate absorbing filter, scattering filter, blocking barrier, or screen that reduces any transmitted laser radiation to levels below the applicable MPE. Exceptions to this section are limited to outdoor uses.

Such laser windows shall be specifically selected to withstand direct and diffusely scattered beams. In this case, the window barrier shall exhibit a damage threshold for beam penetration for a specified exposure time commensurate with the total hazard evaluation for the facility and specific application.

Important in the selection of the window are the factors of flammability and decomposition products of the window material. It is essential that the window not support combustion or release toxic laser generated airborne contaminants (LGAC) following a laser exposure.

4.5.4 Laser Protective Barriers and Curtains (Class 3B and Class 4). A blocking barrier, screen, or curtain that can block or filter the laser beam at the entryway should be used inside the controlled area to prevent the laser light from exiting the area at levels above the applicable MPE. For example, the barrier can be a perimeter guard around all or part of an optical table. In other cases, where the barrier does not extend completely to the ceiling or to the floor, the LSO shall conduct an NHZ analysis to assure safety is afforded to all workers outside the barrier-protected area. There should not be a line of sight from the optics to the entrance way.

Laser barriers shall be specifically selected to withstand direct and diffusely scattered beams. The barrier shall exhibit a damage threshold for beam penetration for a specified exposure time commensurate with the total hazard evaluation for the facility and specific application. The penetration threshold level (PTL) is established as the highest irradiance for which no penetration above the specified attenuation occurs for an exposure of 100 seconds for a given beam spot diameter (see ANSI Z136.7 for additional information).

Important factors in the selection of the barrier are flammability and decomposition products of the barrier material. It is essential that the barrier not support combustion or release LGAC following a laser exposure.

4.5.5 Skin Protection (Class 3B and Class 4). In some laser applications, such as use of excimer lasers operating in the UV, the use of a skin cover shall be employed if chronic exposures are anticipated at exposure levels at or near the applicable MPEs for skin. Due to significant scatter of UV radiation by air molecules, exposure concerns include not only direct beam and diffusely reflected radiation, but atmospheric scatter radiation as well. As the calculation of the intensity of radiation scattered by the atmosphere is impractical, the intensity of such radiation may need to be measured.

Skin protection can best be achieved through engineering controls. If the potential exists for a damaging skin exposure, particularly for UV lasers (295-400 nm) and/or laser welding/cutting applications, skin-covers are recommended. Most gloves will provide some protection against laser radiation. Tightly woven fabrics and opaque gloves provide the best protection. In some cases a laboratory jacket or coat may fulfill the requirement. For Class 4 lasers, consideration shall be given to flame-retardant materials.

For wavelengths greater than 1.4 μm , "large-area" exposures can cause heat loading — causing skin dryness and with excessive exposure, may lead to heat stress (see Section 8.4.2 of ANSI Z136.1-2007). In these cases, personnel exposures shall be minimized.

Chronic skin exposure may have long term adverse health effects that are not fully understood at this time.

4.5.6 Other Personal Protective Equipment. Respirators, additional local exhaust ventilation, fire extinguishers, and hearing protection may be required whenever engineering controls cannot provide protection from a harmful ancillary environment (see Section 7).

4.6 Area Warning Signs.

4.6.1 Design of Signs. Sign dimensions, letter size and color shall be in accordance with ANSI Z535 series.⁶ Figures 1a and 1b show sample signs for Class 2, Class 2M, Class 3R, Class 3B, and Class 4 lasers or laser systems.

4.6.2 Safety Alert Symbols.

4.6.2.1 Laser Symbol Design. There are three similar laser symbol designs for laser signs and labels: all are acceptable for use.

4.6.2.1.1 ANSI Z535 Design. The laser hazard symbol shall be a sunburst pattern consisting of two sets of radial spokes of different lengths and one long spoke, radiating from a common center. This is as specified in the ANSI Z535 series (see safety alert symbol pictured in Figure 1c). The wording can be used for area warning signs only, or alternatively as specified in Section 4.7.3 of ANSI Z136.1-2007.

4.6.2.1.2 IEC 60825-1 Design. The laser hazard symbol shall be composed of an equilateral triangle surrounding a sunburst pattern consisting of two sets of radial spokes of different lengths and one long spoke, radiating from a common center (see Figure 1c). This is as specified in IEC 60825-1.

4.6.2.2 Safety Alert Symbol. A symbol that indicates a potential personal safety hazard. It is composed of an equilateral triangle surrounding an exclamation mark and conforms to ANSI Z535.3.⁷ The symbol is to be located to the left of the signal word on the “Danger” or “Caution” signs. It is not used on the “Notice” signs.

4.6.3 Signal-Words Laser Warning Signs—Purpose (Class 3R, Class 3B, and Class 4).

The purpose of a laser area warning sign is to convey a rapid visual hazard-alerting message that:

- a) Warns of the presence of a laser hazard in the area
- b) Indicates specific policy in effect relative to laser controls
- c) Indicates the severity of the hazard (e.g., class of laser, NHZ extent)
- d) Instructs appropriate action(s) to take to avoid the hazard (e.g., PPE requirements)

The laser warning signs shall utilize warning statements as defined in Section 5 of ANSI Z535.2, where the signal words have the following meanings:

“**DANGER**” indicates an imminently hazardous situation, which if not avoided will result in death or serious injury. This signal word is to be limited to the most extreme conditions.

“**CAUTION**” indicates a potentially hazardous situation, which if not avoided may result in minor or moderate injury. It may also be used to alert against unsafe practices.

“**NOTICE**” is used to indicate a statement of facility policy as the message relates directly or indirectly to the safety of personnel or the protection of property. This signal word shall

⁶ ANSI Z535 Series, National Standard Specification for Accident Prevention Signs.

⁷ ANSI Z535.3, Criteria for Safety Symbols.

not be associated directly with a hazard or hazardous situation and must not be used in place of “DANGER” or “CAUTION.”

“WARNING” is used to indicate a potentially hazardous situation, which if not avoided could result in death or serious injury

The laser area warning signs shall be designed as detailed in 4.6 and are to be posted as required.

The following signal words are used with the ANSI Z535 design laser signs and labels:

4.6.3.1 Danger. The signal word “Danger” shall be used with all signs and labels associated with all lasers and laser systems that exceed the applicable MPE for irradiance, including all Class 3R, Class 3B, and Class 4 lasers and laser systems (see Figure 1b). The OD of LEP at each wavelength for all lasers in use shall be shown on a “Danger” sign for a location requiring the use of eyewear.

4.6.3.2 Caution. The signal word “Caution” shall be used with all signs and labels associated with Class 2 and Class 2M lasers and laser systems that do not exceed the applicable MPE for irradiance (see Figure 1a).

4.6.3.3 Notice. The signal word “Notice” shall be used on signs posted outside a temporary laser controlled area (TLCA), for example, during periods of service (see Figure 1d).

When a TLCA is created, the area outside the TLCA remains Class 1, while the area within may be either Class 3B or Class 4 and the appropriate danger warning is also required within the TLCA (see Figure 1b).

4.6.3.4 Warning. The signal word “Warning” shall be used on signs posted outside the NHZ, TLCA or lifetime testing areas when open beam unattended operation in a non-interlocked area is present. The “Warning” sign may also be used to warn staff of beams crossing walkways.

4.6.3.5 Signal-Words Laser Warning Sign. This is a merge of two laser warning signs (see Figure 1e). It uses the IEC symbol for laser and the ANSI signal word and pertinent sign information as outlined in 4.6.4

4.6.4 Pertinent Sign Information. Sign information and warnings shall conform to the following specifications:

4.6.4.1 The appropriate signal word (Danger, Caution, Warning or Notice) shall be located in the upper panel.

4.6.4.2 Adequate space shall be available on all signs to allow for the inclusion of pertinent information. Such information may be included during the printing of the sign or may be handwritten in a legible manner, and shall include the following:

- a) At position 1 above the tail of the sunburst, special precautionary instructions or protective action that may be applicable. For example:
 1. Laser Protective Eyewear Required
 2. Invisible Laser Radiation
 3. Knock Before Entering

4. Do Not Enter When Light is On

5. Restricted Area

- b) At position 2 below the tail of the sunburst, a combination but not necessarily all of the following: type of laser (Nd:YAG, Helium-Neon, etc.), the emitted wavelength, pulse duration (if appropriate), maximum output, required OD, and
- c) At position 3, the class of the laser or laser system.

NOTE—The word “Radiation” on signs and labels may be replaced by the word “Light” for lasers operating in the visible range at wavelengths greater than 400 nm and equal to or less than 700 nm. For lasers operating outside of this visible range the word “Invisible” should be placed prior to the words “Laser Radiation.”

4.6.4.3 Location of Signs. All signs shall be conspicuously displayed in locations where they best will serve to warn approaching and/or entering personnel.

4.6.4.3.1 Sign for Multiple Lasers in the Same Area. It is not uncommon in the R&D environment to have several lasers, laser systems or wavelengths in use. The LSO may allow any of the following options for signage:

- a) Indicate on warning sign, more than one wavelength may be in use and those entering are required to be informed by the laser user of the correct eyewear or precautions to follow
- b) Post a sign per laser
- c) List up to five lasers or wavelengths per sign
- d) List all lasers or wavelengths and have a means to indicate that are in present use

4.6.5. Existing Signs and Labels. Signs and labels prepared in accordance with current or previous versions of ANSI Z136.1 are considered to fulfill the requirement of this standard.

4.7 Laser Disposal.

There are four basic ways to dispose of lasers that are no longer being used. The first method is to give/donate the laser to an organization that can use it. Such organizations might include schools, industrial companies and hospitals. The donor should assure that the laser equipment being given complies with all applicable product safety standards, such as the FLPPS (Federal Laser Product Performance Standard), and has provided adequate safety instructions for its operations and maintenance to the recipient. The donor should ensure that the laser will be used by individuals who are trained in laser safety. Personnel should also be aware of their institutional policies regarding transfer or donation of such equipment; it may be necessary to review the matter with their legal department or general counsel. The second approach would be to return the laser to the manufacturer for credit toward the purchase of a new laser, if applicable, or to a vendor specializing in recycling (re-selling or refurbishing) used laser equipment. The third method is to eliminate the possibility of activating the laser by removing all means by which it can be activated (e.g., cutting/removing electrical connections between a laser’s head and its power supply). Once this has happened the laser could then be disposed of. The fourth method would be to destroy the laser.

The last two methods could be subject to landfill restrictions due to the possibility of hazardous materials being found inside the laser system's components, such as mercury switches, oils, laser media (e.g., cadmium vapor in a HeCd laser) and other hazardous chemicals.

5. Education and Training

5.1 General.

A thorough understanding of laser radiation hazards by people working with lasers is an essential component of a safe laser work environment. The degree of understanding shall include, at a minimum, all of the specific hazards a person will be potentially exposed to during their laser activities, generally determined by a complete hazard evaluation of their laser work environment (see Section 3 for laser hazard evaluation steps and Section 7 for non-beam hazards and controls). Laser users shall be able to evaluate hazards in a dynamic environment and shall be aware of the types of activities that have been involved in laser accidents, and that most laser accidents are a result of user manipulation of objects in the beam path. The supervising organization shall ensure that laser users have the required knowledge to work safely, through evaluation, testing, training and auditing of controls.

Training shall be provided to each LSO, Deputy LSO and employee routinely working with or potentially exposed to Class 3B or Class 4 laser radiation. Awareness training should be provided to employees working with or potentially exposed to Class 1M, Class 2, Class 2M, or Class 3R laser radiation. The level of training shall be commensurate with the degree of potential laser hazards, both from the laser radiation and non-beam hazards.

5.2 Refresher Training.

The supervising organization shall address the needs for maintaining the appropriate level of laser safety proficiency through the use of periodic training. Overseeing compliance of refresher training is generally the responsibility of the LSO, Laser Safety Committee or a training component of the supervising organization.

The implementation and frequency of this training should be based on evaluation of the laser hazards involved and the depth of knowledge and skill of each laser user. For instance a person routinely building custom Class 4 lasers does not require testing or training on the fundamentals of laser operation, but a review of laser accidents and biological effects might aid in reducing complacency with laser hazards. A person not routinely working with lasers might require more extensive refresher training including institutional controls, use of control measures, hazard evaluation and safe work practices.

Refresher training can be an abbreviated version of the original training, or a review of laser safety based lessons learned. Whatever form refresher training takes, the end result should be that the users have the necessary and documented laser safety awareness and knowledge to continue to work safely with lasers.

5.3 Hands-on Training aka On-the-Job Training (OJT).

By nature, the R&D environment frequently involves dynamic laser setups and therefore changing hazards. Frequently alignment and operation procedures are developed and not always documented in a formal SOP since the procedure is dynamic. It is essential for laser user protection that new or less involved staff be provided with hands-on training by an individual fully cognizant of the nature of the work and the hazards involved (e.g., wavelengths, what and how reflections are to be blocked). Documentation of this training is advantageous, but is to be determined by the supervising organization.

5.4 Trainer Qualifications.

Evaluation, testing, and training shall be conducted by individuals or technologies (on-line training) with skills adequate and appropriate to the subject matter. For instance this would include, but not be limited to: knowledge of laser(s), laser safety concepts, biological effects, laser safety standards, and the organization's laser safety program requirements.

NOTE—Experience has shown that the important factors are experience with lasers, good presentation skills, and a thorough knowledge of the applicable standards. For web based, or on-line training, interactive activities enhance the learning process.

5.5 LSO Training.

Management shall provide for LSO and Deputy LSO training on the potential hazards including bioeffects, control measures, applicable standards, medical surveillance (if applicable) and any other information pertinent to laser safety and applicable standards, or shall provide to the LSO adequate consultative services. The training shall be commensurate to at least the highest class of laser under the jurisdiction of the LSO. The LSO shall be required to complete refresher training.

5.6 User Evaluations and Training.

Laser users, including operators, technicians, engineers, maintenance and service personnel, require detailed knowledge about the potential hazards, control measures, and safe work practices for the laser system he/she will be working with and shall receive training commensurate with the greatest level of potential laser radiation exposure.

All users of Class 3B and/or Class 4 laser or laser systems shall have adequate knowledge of all pertinent laser safety subjects. Management shall ensure this through documented user evaluation, testing or training. The LSO needs to review the effectiveness of this training and make any modifications if deemed inadequate. Users of lower class lasers should be provided with evaluation or training commensurate with the degree of potential laser radiation exposure. This training can take place as part of new employee orientation.

The training shall ensure that the users are knowledgeable of the potential hazards and the control measures for laser equipment they may have occasion to encounter. All training shall be commensurate with the highest potential for laser radiation exposure associated with each laser operation, and shall be consistent with the results of the completed hazard evaluation as performed in accordance with Section 3 of this standard, which considers the laser, the environment, and the personnel. OJT training shall be required for all personnel likely to

encounter exposure levels above the Class 3R MPE. Training shall include safety procedures for applicable non-beam hazards associated with laser systems in use.

6. Medical Examinations

6.1 Ocular Medical Examinations.

For Class 3B and Class 4 laser personnel, and as prescribed by institutional policy or state regulations, medical examination should be performed prior to participation in laser work. Neither periodic nor termination examinations are required.

6.2 Examinations Following a Suspected or Actual Laser-Induced Injury.

Medical examinations shall be performed as soon as practical (usually within 48 hours) when a suspected injury or adverse effect from a laser exposure occurs. In addition to the acute symptoms, consideration shall be given to the exposure wavelength, emission characteristics of the laser, and exposure situation to assure appropriate medical referral. See Appendix E for recommended medical referral following suspected or known laser injury commensurate with the observed symptoms and laser system. For injury to the eye from lasers operating in the retinal hazard region, examinations shall be performed by an ophthalmologist or retinologist.

6.3 Medical Surveillance.

Medical laser surveillance is not recommended for personnel using Class 1, Class 1M, Class 2, Class 2M or Class 3R lasers and laser systems, and is at the discretion of the institution for Class 3B and Class 4 lasers and laser systems.

6.4 General Procedures.

The protocol for a baseline eye examination:

Ocular history. If the ocular history shows no problems and visual acuity is found to be 20/20 (6/6 in each eye for far and near) with corrections (whether worn or not), and Amsler Grid Test and Color Vision responses are normal, no further examination is required. Laser workers with medical conditions should be evaluated carefully with respect to the potential for chronic exposure to laser radiation. Any deviations from acceptable performance will require an identification of the underlying pathology either by a fundusoscopic examination or other tests as determined appropriate by the responsible medical or optometric examiner. (See also Appendix E of ANSI Z136.1.)

6.5 Skin Evaluation.

Laser users chronically exposed to artificial sources of UV radiation (e.g., excimer, HeCd, Nitrogen, third harmonic Nd:YAG laser radiation, bio-safety hood lights) should obtain an annual skin cancer screening.

7. Non-Beam Hazards

7.1 General.

Non-beam hazards (NBH) are all hazards arising from the presence of a laser system, excluding human exposure to direct or scattered laser radiation. NBH include physical, chemical, and biological agents that may occur when a material is exposed to a laser beam (e.g., fire or airborne contaminants), when materials used to generate the beam (e.g., flow-through gases, dyes and solvents) are released into the atmosphere, or when individuals contact system components (e.g., shock or electrocution). See Appendix F for information and suggested guidance on physical, chemical and biological NBH.

Some NBH can be life threatening (e.g., electrocution) and may require use of more stringent control measures than those discussed in Section 4.

All written SOPs shall address NBHs as well as beam hazards.

Due to the diversity of the NBH, the LSO may need to seek the assistance of safety and/or industrial hygiene personnel.

7.2 Miscellaneous Non-beam Hazards.

7.2.1 General. Miscellaneous NBHs not previously discussed and warranting consideration include laser-related waste and the degradation (or malfunction) of cooling systems serving laser systems.

7.2.2 Laser-related Waste. Proper waste disposal of contaminated laser-related material, such as flue and smoke filters, organic dyes, and solvent solutions shall be handled in conformance with appropriate federal, state, and local guidelines consistent with the institutional policies (e.g., a chemical hygiene plan). The need for such conformance would also apply to the disposal of containers of hazardous gases (e.g., compressed gas cylinders) or their precursors (e.g., in situ hazardous gas generating systems) used in lasers and laser applications.

7.2.3 Degradation/Malfunction of Laser Cooling Systems. Lasers can produce as much as 2-1000 watts of heat for every watt of optical power generated. In order to control this heat, laser manufacturers design laser systems to be conductivity-cooled, air-cooled, or cooled with a closed-loop chiller. A chiller is a system designed to remove a certain heat load at a given temperature. It is recommended that users consult the manufacturer to obtain information on cooling approaches before activating the laser. If cooled water is used to aid in reducing heat loads, it may be useful to filter the incoming water to ensure that minerals and particulate matter are removed to minimize damage to laser-supporting cooling equipment or its malfunction. This consideration may apply to the laser power supply itself and/or some other laser system component (e.g., a target irradiated by the laser's beam).

7.2.4 Building Codes. Consideration needs to be given to local building codes that many times reflect local natural phenomena (e.g., earthquake, hurricane, tornado, high winds) as well as local fire codes, ventilation controls, chemical storage and seismic controls.

8. Criteria for Exposures of Eye and Skin

MPEs are the level of laser radiation to which an unprotected person may be exposed without adverse biological changes in the eye or skin. In the R&D setting, laser parameters such as pulse duration may be outside of evaluated MPE values. In these cases extra care must be taken by the user as it applies to possible exposure. Beam containment, remote manipulation and monitoring and other engineering controls should be the first lines of defense. LEP selection is an even greater challenge than usual. The most current information on criteria for exposure of the eye and skin will be found in ANSI Z136.1. Exposure to levels at the MPE may be uncomfortable to view or feel upon the skin. Thus, it is good practice to maintain exposure levels sufficiently below the MPE to avoid discomfort. Distractions resulting from laser beam exposure, such as flash-blindness, glare, and startle, which can create secondary hazards, have become an increasing concern. These low-level effects are not covered in this standard, but are covered for nighttime use in FAA Order 7400.2 and ANSI Z136.6.

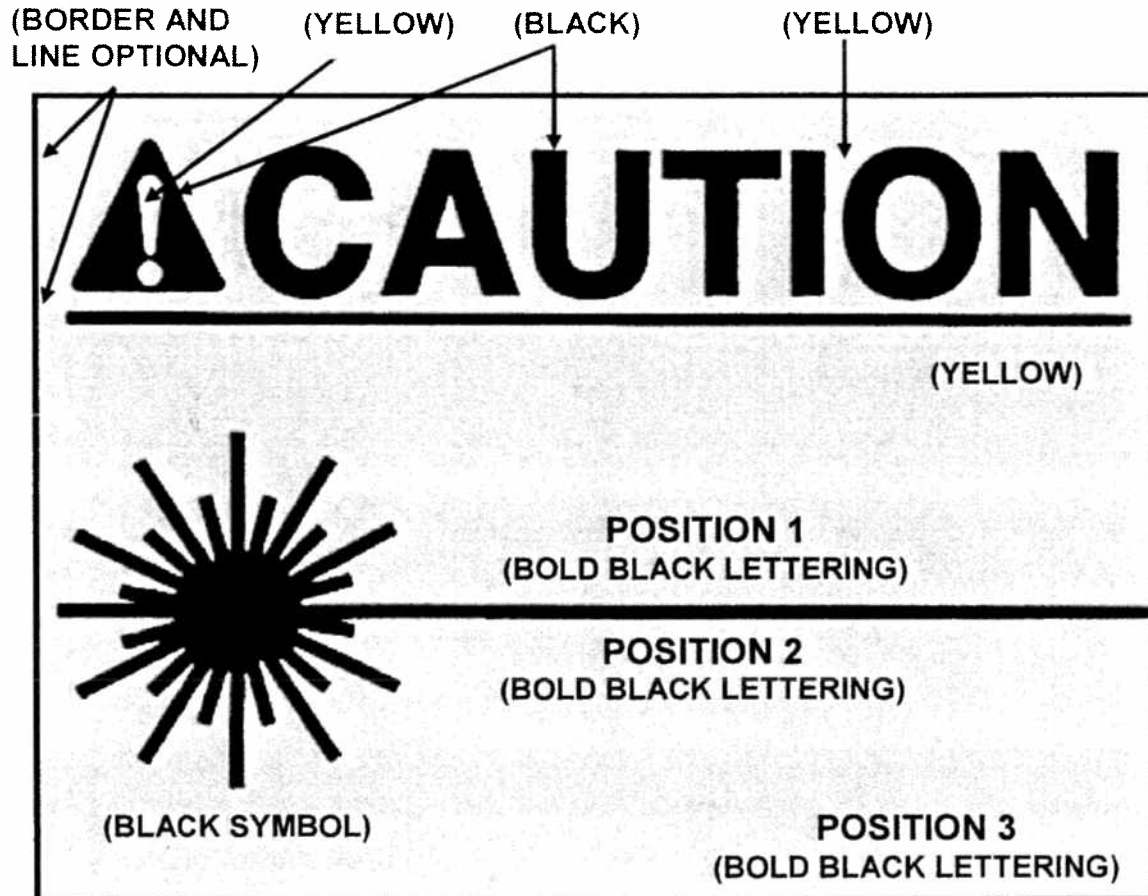


Figure 1a. ANSI Z136.1 Compliant Sample Warning Sign for Class 2 and Class 2M Lasers

NOTE—This sample sign format is not compliant with the current version of ANSI Z535.2.

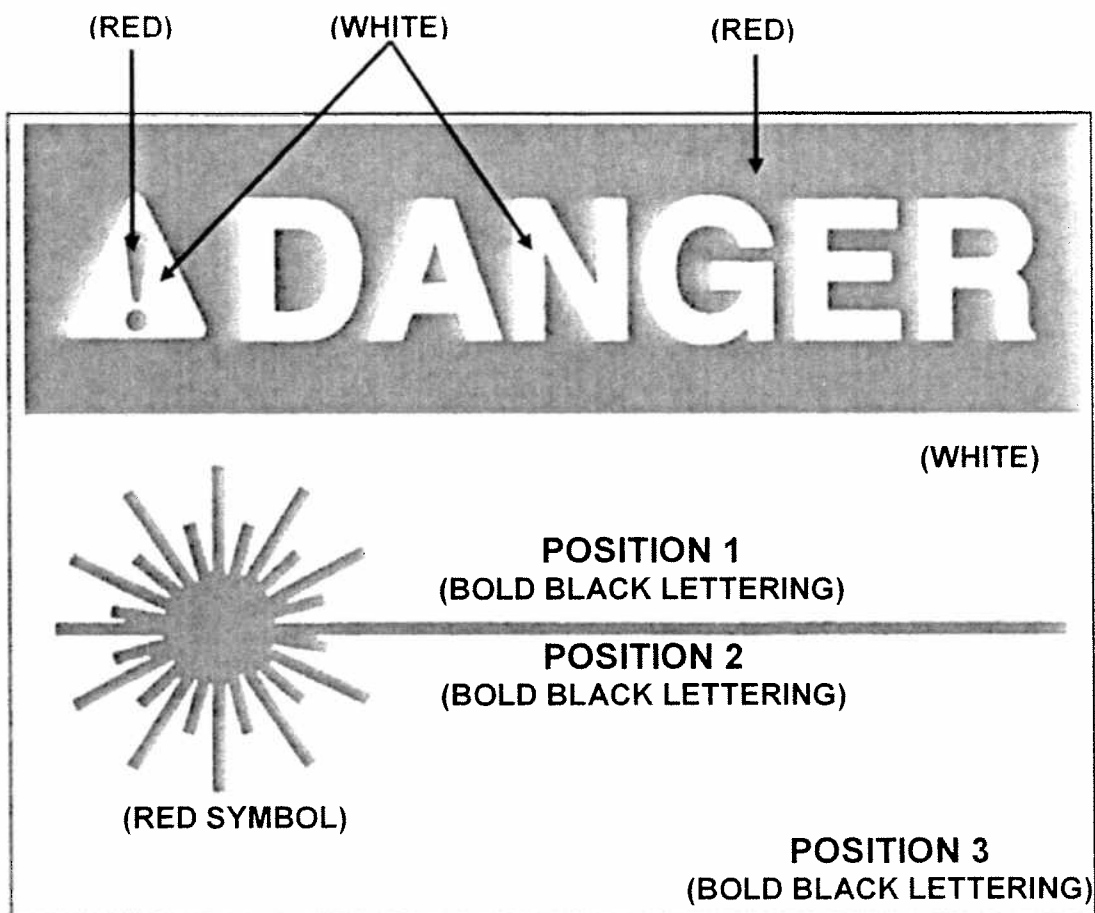


Figure 1b. ANSI Z136.1 Compliant Sample Warning Sign for Class 3R, Class 3B, and Class 4 Lasers

NOTE—This sample sign format is not compliant with the current version of ANSI Z535.2.

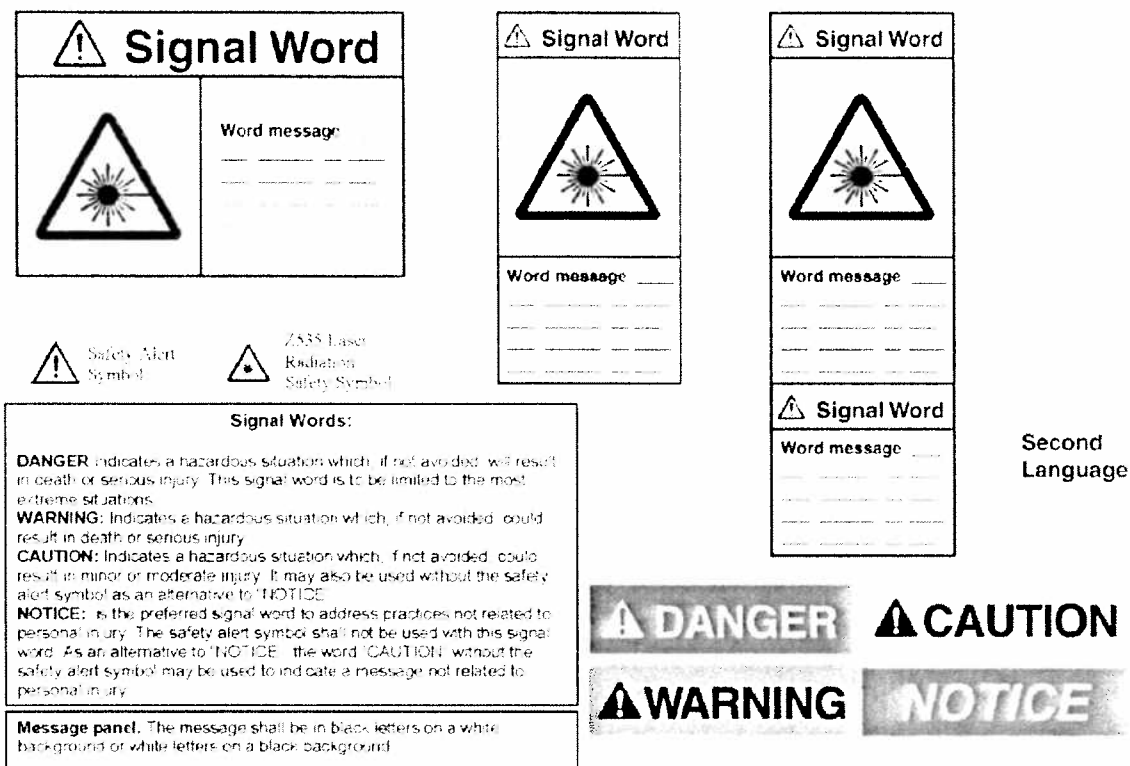


Figure 1c. ANSI Z535.2 Compliant Laser Area Warning Sign Formats

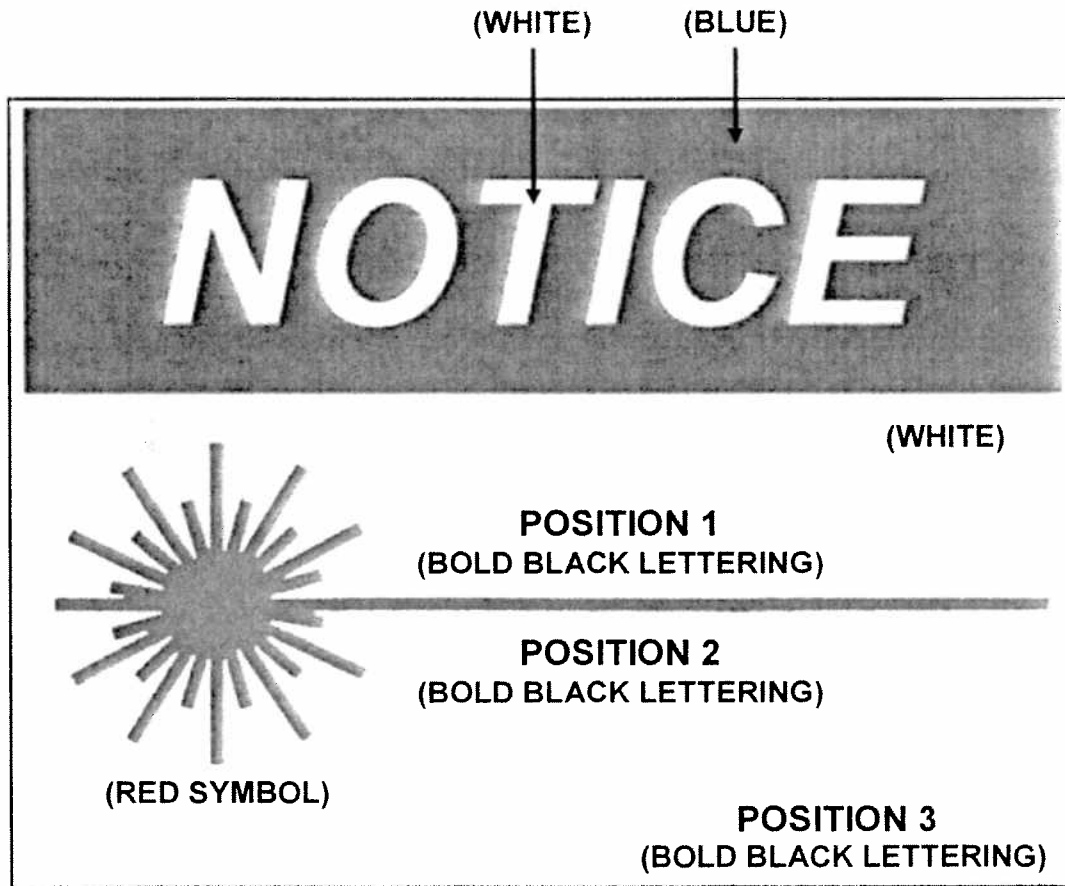


Figure 1d. ANSI Z136.1 Compliant Sample Warning Sign for Facility Policy, e.g., Outside a Temporary Laser Controlled Area During Periods of Service

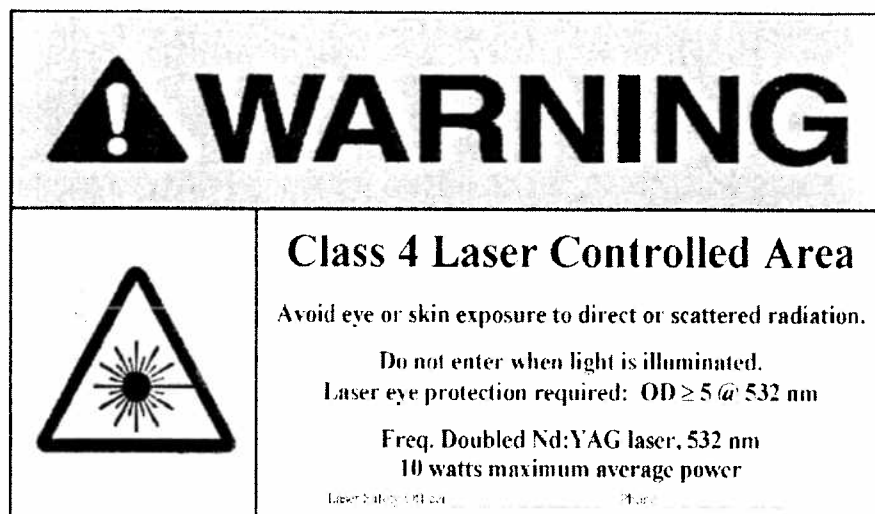


Figure 1e. Sample Warning Sign for Class 3B and Class 4 Lasers

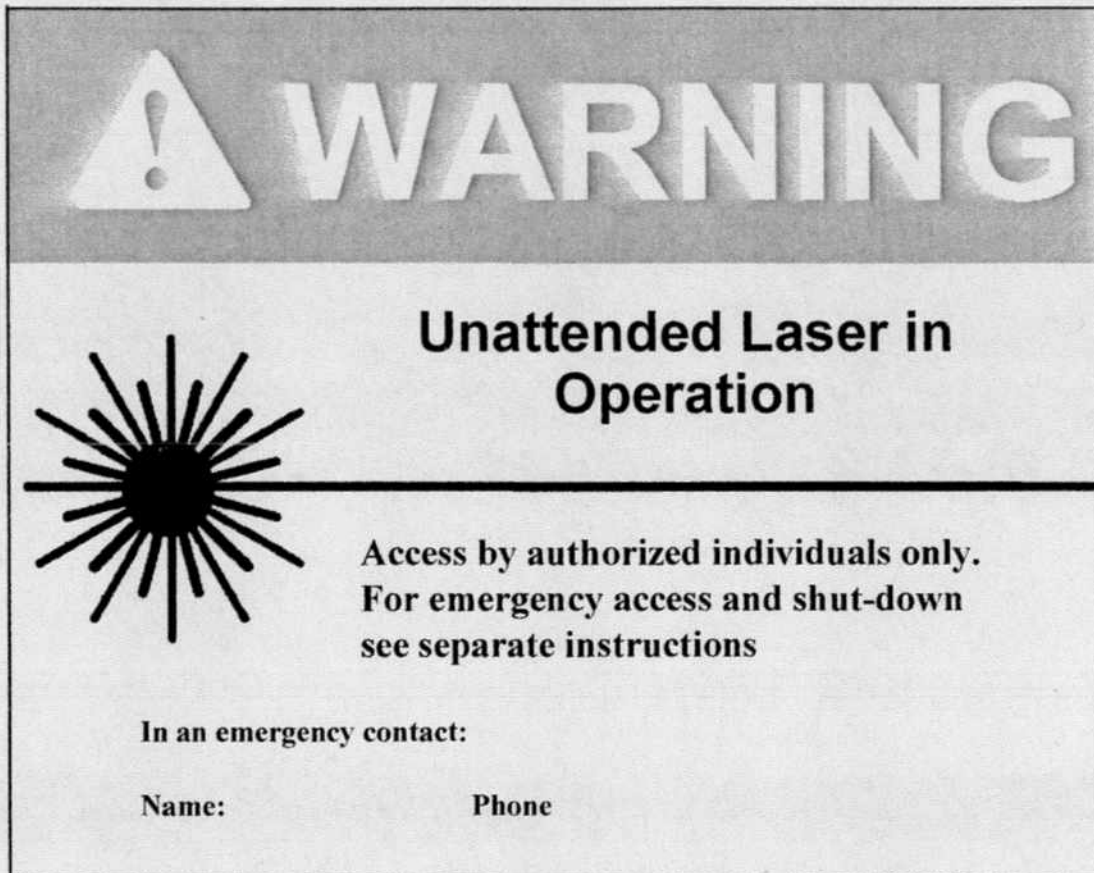


Figure 1f. ANSI Z136.1 Compliant Sample Warning Sign for Facility with Unattended Laser Open Beam in Operation

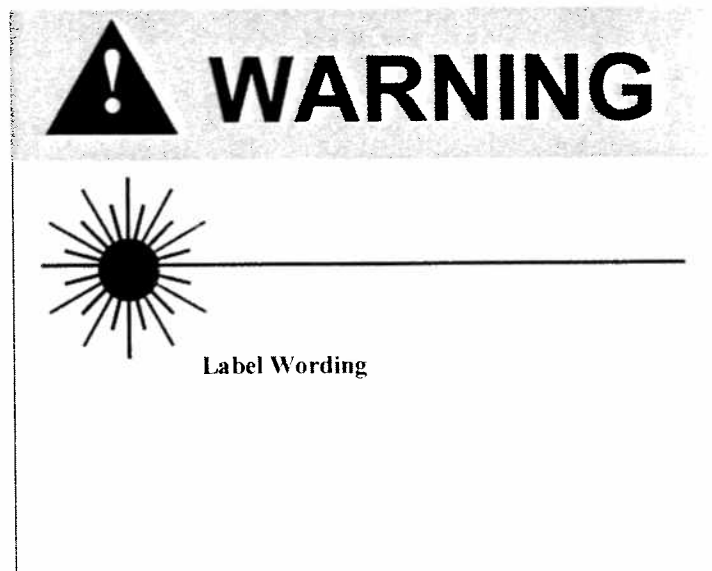
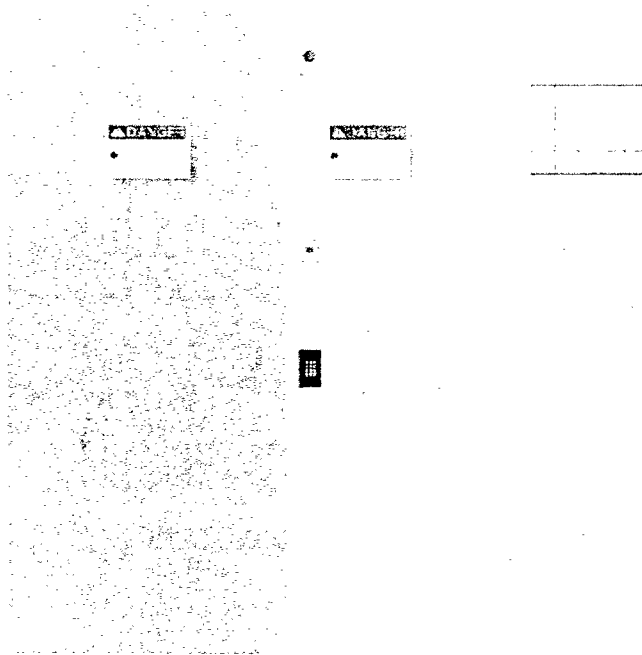


Figure 1g. Warning Awareness Label

Wording could indicate:

- Vertical Beams
- Polarizer Caution
- Barrier does not provide laser protection, cleanliness only
- Non-interlocked housing



**Figure 2a. Exterior of LCA Entryway Safety Controls
for Class 4 Lasers Utilizing Entryway Interlocks**

Elements of Figure 2a, LCA entrance

- Printed laser warning sign on door
- Illuminated laser area warning sign on side of door, near eye height, not over 2 m (6 ft) from the floor
- Eyewear holder (can be located either inside or outside of LCA or both locations)
- Key pad for interlock by-pass or authorized user entry
- Door bell, intercom or permission-to-enter device
- Emergency entry device (unlocks door, may drop power or laser shutters), place out of random reach (or guarded to prevent random activation)

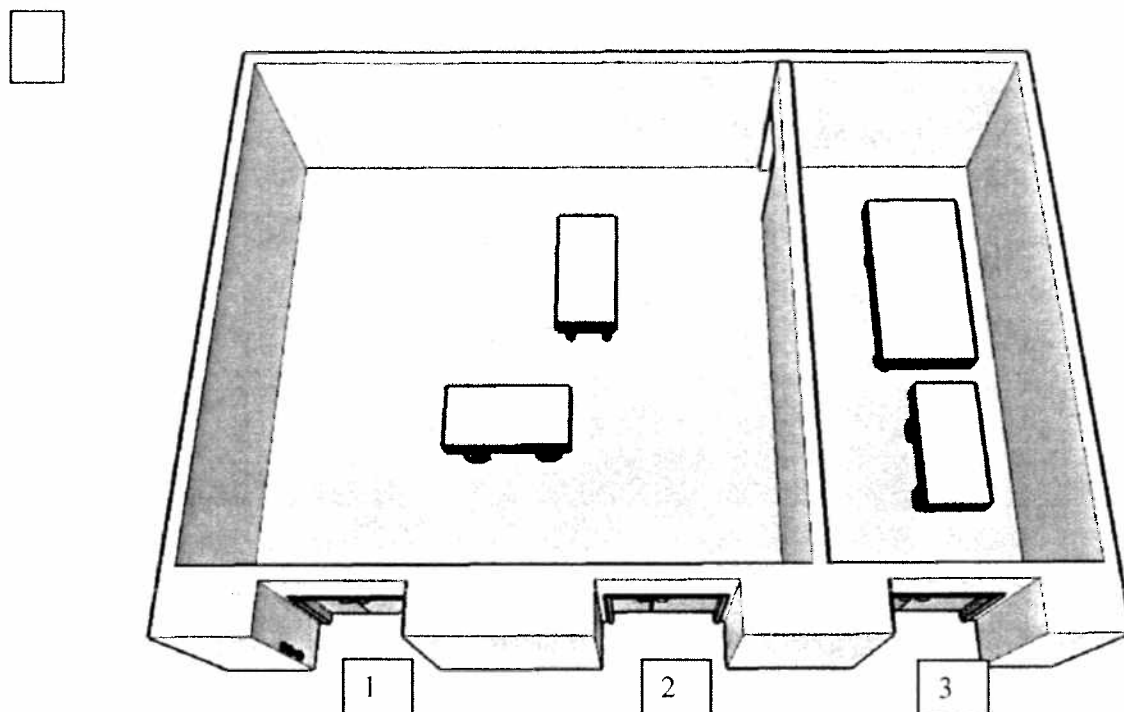


Figure 2b. LCA – Multi-Entry Points

- Laser protective eyewear can be stored outside or inside laser room. If inside, must be near entrance and beam exposure of personnel at or near entrance must be precluded.
- Door 1 is main entrance
- Door 2 is only for equipment movement, access control-lock door, remove outer door handle, non-defeatable interlock
- Door 3 separate lab
- Interconnecting door should be labeled “Emergency Exit Only” on both sides, can be non-defeatable interlock to laser system
- Illuminated area warning light should be eye height (less than 6 feet from the floor)

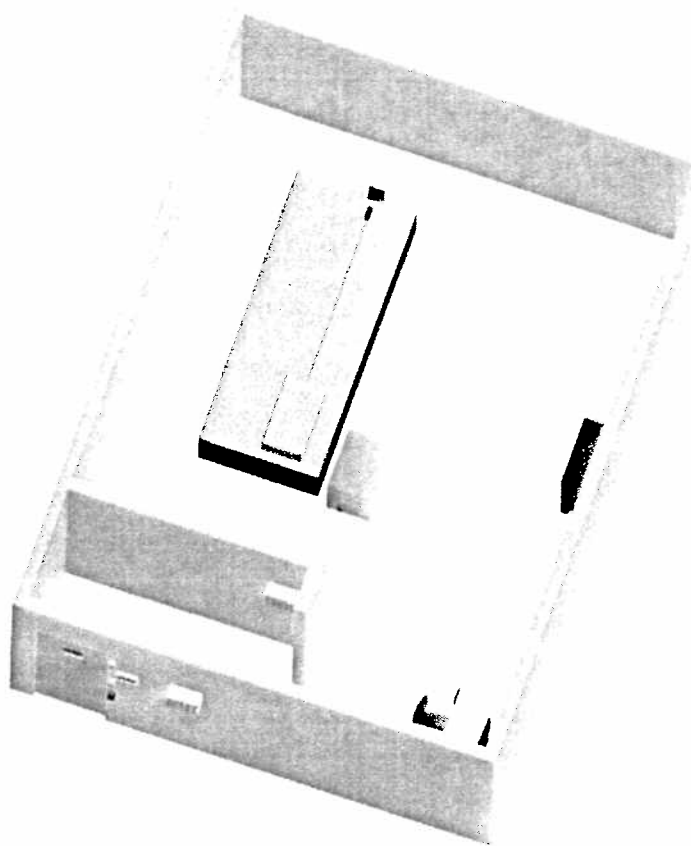


Figure 2c. LCA Entryway Safety Controls for Class 4 Laser Entryway Interlocks. Design also applicable for non-interlocked room.

Key features:

- Area warning sign on door
- Illuminated sign next to door indicating laser status
- Barrier inside room, protects individual upon entry, provides a location to put on PPE, (e.g., eyewear, clean room clothes). Prevents beams from exiting room. Great location for binder with SOP and notices—barrier not the common approach, usually door opens right into lab space.
- Care is needed to ensure beams are blocked and stay on optical table.
- Key pad or other by-pass device
- Laser protective eyewear holder, inside and out, either is acceptable
- Emergency entrance button
- Beam blocks end of beam path

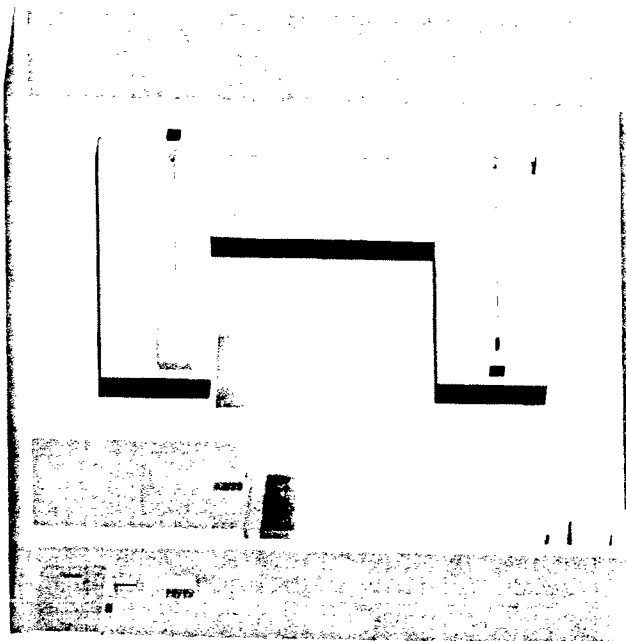


Figure 2d. LCA Entryway Safety Controls for Class 4 Lasers without Entryway Interlocks. Design also applicable for non-interlocked room.

Key features:

- Area warning sign on door
- Illuminated sign next to door indicating laser status (e.g., standby, operated, off)
- Maze (“Dog leg”) entry. Protects individual upon entry, provides a location to put on PPE (e.g., eyewear, clean room clothes). Great location for binder with SOP and notices.
- Barrier not the common approach, usually door opens right into lab space. Care is needed to make sure beams are blocked and stay on optical table.
- Notice laser set up has beams aimed away from entry
- Beam blocks at end of beam path and turning optics

Appendix A

Supplement to Section 1 – Laser Safety Programs

A1. Laser Facility

A1.1 General. The laser facility is a facility in which lasers are operated for any purpose. It is the responsibility of the laser facility management to have a laser safety program in place based on the types and uses of its operated lasers and laser systems.

The laser facility shall ensure that there is a mechanism in place (such as a designated individual or a committee) that is ultimately responsible for all phases of a laser project that requires LSO oversight.

A2. Laser Safety Officer (LSO)

A2.1 General. The LSO is an individual designated by the employer with the authority and responsibility to effect the knowledgeable evaluation and control of laser hazards and to monitor and enforce the control of such hazards. The LSO shall have authority to suspend, restrict, or terminate the operation of a laser system if he/she deems that laser hazard controls are inadequate. For the laser safety program to be effective, the LSO must have sufficient authority commensurate with the responsibility. In organizations that do not permit authority to reside with non-management personnel and the LSO is a non-management position, the management shall provide protocols and reporting structure to assure adequate enforcement authority.

The LSO may be designated from among such personnel as the radiation safety officer, industrial hygienist, safety engineer, laser specialist, laser operator or user. The LSO may be a part-time position when the workload for an LSO does not require a full-time effort. In some instances, the designation of an LSO may not be required. Operation and maintenance of Class 1, Class 1M, Class 2, Class 2M and Class 3R lasers and laser systems normally do not require the designation of an LSO. However, under some circumstances it may be desirable to designate an LSO, for example, if service is performed on a laser system having an embedded Class 3B, or Class 4 laser or laser system. In such instances, management may designate the service person requiring access to the embedded laser as the LSO. In any case, there shall be a designated LSO for all circumstances of operation, maintenance, and service of Class 3B and Class 4 lasers or laser systems.

If necessary, a Deputy Laser Safety Officer (DLSO) or Back up Laser Safety Officer (BLSO) shall be appointed by management or the LSO. The DLSO/BLSO shall perform the functions of the LSO when the latter is not available. For institutions with multiple divisions, plant locations and multi-shifts, a system of DLSOs may be required to carry out the duties of the LSO at those locations or during the shifts.

A2.2 LSO Specific Duties and Responsibilities.

- a) **Safety Program.** The LSO shall establish and maintain adequate policies and procedures for the control of laser hazards. These policies and procedures shall comply with applicable requirements, including federal, state and local regulations.

- b) **Classification.** The LSO shall classify, or verify classifications of lasers and laser systems used under the LSO's jurisdiction. Classifications shall be consistent with classifications listed in Section 3 of this standard.
- c) **Hazard Evaluation.** The LSO shall be responsible for hazard evaluation of laser work areas. Hazard evaluation shall be conducted in accordance with Section 3 of this standard.
- d) **Control Measures.** The LSO shall be responsible for assuring that the prescribed control measures are implemented and maintained in effect. This includes avoiding unnecessary or duplicate controls and recommending or approving substitute or alternate control measures when the primary ones are not feasible or practical.
- e) **Procedure Approvals.** The LSO should approve Class 3B and shall approve Class 4 SOPs, and other procedures that may be part of the requirements for administrative and procedural controls.
- f) **Protective Equipment.** The LSO shall recommend or approve PPE, including eyewear, clothing, barriers and screens, as may be required to assure personnel safety. The LSO shall assure that protective equipment is audited periodically to assure proper working order.
- g) **Environmental and Facility Safety Signs and Equipment Labels.** The LSO shall review the wording on area signs and equipment labels.
- h) **Facility and Equipment.** The LSO shall review Class 3B and Class 4 laser installations, facilities and laser equipment prior to use. This also applies to modification of existing facilities or equipment.
- i) **Training.** The LSO shall assure that adequate safety education and training are provided to laser personnel that are potentially exposed to laser radiation exceeding the MPE. The LSO should make available adequate safety education and training to personnel working with or around lasers that do not produce exposures that exceed the MPE. The frequency of refresher training shall be considered on the basis of the total hazard evaluation criteria presented in Section 3.
- j) **Approval of Alignment Eyewear.** The LSO on a case-by-case basis should review the need and use of alignment eyewear by the laser user. Alternate means of viewing the beam such as CCD and web cameras should be considered before allowing the use of alignment eyewear.
- k) **Medical Surveillance.** The LSO shall determine the personnel categories for medical surveillance (see Section 6).
- l) **Records.** The LSO shall assure that the necessary records required by applicable federal, state and local regulations are maintained. The LSO shall also submit to the appropriate medical officer the individuals' names that are obtained in accordance with A4.1(c) and A4.1(d), and shall assure that the appropriate records are maintained indicating that applicable medical examinations have been scheduled and performed. Other records documenting the maintenance of the safety program, such as training records, audits, and SOP approvals, shall be maintained.

- m) **Audits, Surveys and Inspections.** The LSO shall periodically audit or survey by inspection for the presence and functionality of the laser safety features and control measures required for each Class 3B and Class 4 laser or laser system in the laser facilities. The LSO shall accompany regulatory agency inspectors (such as OSHA, FDA/CDRH, state or local agencies) reviewing the laser safety program or investigating an incident and document any discrepancies or issues noted. The LSO shall assure that corrective action is taken where required.
- n) **Accidents.** The LSO should develop a plan to respond to notifications of incidents of actual or suspected exposure to potentially harmful laser radiation. The plan should include the provision of medical assistance for the potentially exposed individual, investigation of the incident and the documentation and reporting of the investigation results.
- o) **Approval of Laser Systems Operations.** Approval of Class 3B and Class 4 lasers and laser systems for operation shall be given only if the LSO is satisfied that laser hazard control measures are adequate. This includes all required SOPs for Class 3B and 4 laser systems. The procedures should include adequate consideration of safety from non-beam hazards.

A3. Laser Safety Committee

A3.1 Membership of Laser Safety Committee. The membership of the Laser Safety Committee may include members with expertise in laser technology or in the assessment of laser hazards. Management may be included in the membership. Examples of members include, but are not limited to the following: technical management, LSO and/or representatives of the safety/industrial hygiene organization, physician, education department member, engineer/scientist and user representative.

A3.2 Policies and Practices. The committee shall establish and maintain adequate policies and practices for the evaluation and control of laser hazards, including recommendations for appropriate laser safety training programs and materials.

A3.3 Standards. The committee shall maintain an awareness of all applicable new or revised laser safety standards.

A3.4 Deputy Laser Safety Officer (DLSO). At the discretion of the LSO or management a DLSO may be designated. This person may also be known as the laser safety supervisor. This individual can be responsible for laser safety for a division, building or individual laser use area. The responsibility of this person is similar to the LSO or supervisor. They are responsible for day-to-day laser safety operation and should have training commensurate to their duties.

A3.5 Deputy Laser Safety Officer Committee. At the discretion of the LSO or management, a DLSO committee may be created. The goal of such a committee is to ensure that consistent policies are followed throughout an organization and for continued education of the DLSO(s). Policies and procedures should mirror those of the Laser Safety Committee.

A4. Other Personnel Responsibilities

A4.1 Laser Supervisor/Laser Safety Supervisor. The supervisor (work area leader, group leader, and foreman) of individuals working with or having the potential for exposure to greater than Class 1 laser radiation, should have a basic overall knowledge of laser safety requirements for the lasers under his or her authority.

The following should be considered a minimal set of responsibilities for the Laser Supervisor:

- a) The supervisor shall be responsible for the issuance of appropriate instructions and training materials on laser hazards and their control for all personnel who may work with lasers that are operated within the supervisor's jurisdiction.
- b) The supervisor shall not permit the operation of a laser unless there is adequate control of laser hazards to employees, visitors, and the general public.
- c) The supervisor shall submit to the LSO the names of individuals scheduled to work with lasers and shall submit information as requested by the LSO for scheduling medical surveillance and completion of training.
- d) When the supervisor knows of, or suspects, an accident resulting from a laser operated under his or her authority, the supervisor shall immediately upon becoming aware of the suspected laser incident implement the institution's accident responsibility plan and ensure it includes notification of the LSO.
- e) If necessary, the supervisor shall assist in obtaining appropriate medical attention for any employee involved in a laser accident.
- f) The supervisor shall not permit operation of a new or modified Class 3B or Class 4 laser under his or her authority without the approval of the LSO.
- g) The supervisor shall submit plans for Class 3B and Class 4 laser installations or modifications of such installations to the LSO for review.
- h) For Class 3B and Class 4 lasers and laser systems, the supervisor shall be familiar with the SOPs and ensure that they are provided to users of such lasers.

A4.2 Responsibility of Employees Working with Lasers. Employees working with lasers or laser systems shall have, where applicable, the following minimal responsibilities.

- a) An employee shall not energize or work with or near a laser unless authorized to do so by the supervisor for that laser.
- b) An employee shall comply with safety rules and procedures prescribed by the supervisor and the LSO. The employee shall be familiar with all applicable operating procedures.
- c) When an employee operating a laser knows or suspects that an accident has occurred involving that laser, or a laser operated by any other employee, and that such accident has caused an injury or could potentially have caused an injury, he or she shall immediately inform the supervisor. If the supervisor is not available, the employee shall notify the LSO.

A4.3 Other Personnel. Anyone involved in purchasing a laser or laser system should contact the LSO. Such personnel may also include, but is not limited to, purchasing, accounting, and building management as may be applicable.

A4.4 Responsibility of Additional Safety Professionals. Environmental Health & Safety (EH&S) Professionals provide guidance in handling and establishing controls for laser-associated hazards such as:

- Laser dyes and other toxic chemicals
- Ventilation requirements for laser targets and toxic materials
- Hazardous gases
- Electrical hazards
- Seismic hazards

Appendix B Sample Forms

B1. Examples of Typical Lasers Lab Hazard Evaluation Forms

Form B1. Laser Operations Safety Audit Form

Auditor: _____ SOP#: _____ Audit Date: _____

Type of Audit: ☐ Annual ☐ New ☐ Amend ☐ Self-Assessment ☐ Other

Facility Name: _____ Building: _____ Rooms: _____

Responsible Individual: _____

Room Contact During Audit: _____

Classes of Lasers in this room(s) ☐ Class 4 ☐ Class 3B ☐ Class 3R ☐ Class 2 ☐ Class 1 embedded

Posted Documentation and Security Measures

1. Access door interlocks & status panel functional:	<input type="checkbox"/> Key	<input type="checkbox"/> Code	Comments: _____	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
2. Access door signs current format; emergency contact current:			Comments: _____	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
3. Posting on ancillary doors:				<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
4. Current SOP available:				<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
5. Eyewear requirements posted:				<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
6. Interlock check sheet available & current:				<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
7. Alignment procedure (class 3b & 4):				<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
8. Interlock check procedures available for complicated systems:				<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
9. Inventory accurate or per signage:				<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
10. Written interlock procedure:				<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA

Laser Unit Safety Controls:

11. Laser classification labels present on commercial units:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
12. Protective housings in place:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
13. Beam shutters interlocked & functioning as per interlock check sheet:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
14. Interlock bypass functioning (=15 seconds):	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA

Engineering and Administrative Laser Safety Controls:

15. Lasers & optics secured to table:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
16. Beam properly contained (Not a hazard to persons sitting or standing):	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
17. Beams enclosed where available. Perimeter guards, beam tubes:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA

18	Housekeeping, general appearance:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
19	Adequate controls where beams leave tables or leave enclosures:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
20	Marks on walls:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
21	Windows/door openings covered:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
22	Beams blocked from open by-passed doors:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
23	Non-essential reflective materials out of beam paths & surroundings:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
24	Administrative controls employed, barriers, demarcated:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
25	Upward directed beams are labeled:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
Other Safety Measures				
26	Laser eye exams by all personnel (3b and 4 lasers):	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
27	Proper eyewear available for all personnel, ODs OK?:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
28	Proper storage of eyewear, where?:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
29	Proper skin protection available and employed:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
30	Are all current users trained?	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
31	Collecting optics used (microscopes, binoculars, telescopes):	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
Non-beam Hazards				
32	High voltage hazards minimized:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
33	Optical tables bonded to building ground:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
34	Optical tables seismically secured: (if no, how many?):	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
35	Housekeeping fire hazards minimized:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
36	Good housekeeping on optical tables:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
37	Fiber optic use:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
38	Container for fiber sharps:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
39	Fiber ends/connectors labeled:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
40	Fiber conduit labeled:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA
41	Other non-beam hazards minimized:	<input type="checkbox"/> Y	<input type="checkbox"/> N	<input type="checkbox"/> NA

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it is intended for information only.

Fabrication Area

Comments

Auditor signature

Date

This appendix is not a normative appendix;
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This appendix is not normative appendix;
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Form B2. Administration Information

Auditor: _____ Date: _____ PI: _____ Division: _____
Laser supervisor (POC): _____ Building: _____ Room: _____
Reason for audit: _____
Present during audit: _____

Documentation

All lasers listed in SOP (circle): Yes No
Warranty contract Name, vendor _____
Laser information _____
Highest Class laser (circle) 3B 4
Lasers in storage _____

Alignment lasers in use (circle): Y N Type/Quantity _____ HeNe _____ Diode _____ IR _____
New laser(s) (list with specifications on last page): _____

Environment

Main entrance door posted: _____
Posting accurate (wavelength): _____
Contact information: _____
Readably visible: _____
Ancillary doors: _____
Entry through curtain: _____

Windows and doors coverings:				
Illuminated sign:				
Functional				
How visible:	Bright	Average	Dim	
Access control				
Administrative means				
Explain:				
Interlocked:				
Non-defeatable:				
(Outside by-pass available (circle))	Card key	Key pad	Key	Other
E-stop present:				
Last interlock check date				
Interlock functioning				
Written interlock check procedure				
Interlock to shutters				
Interlock to power supply:				
Housekeeping				
On optical table				
In laser use area				
Unattended operation				
Post unattended sign				
Beam path				
Beam path (circle):	Totally open	Completely enclosed	Combination	

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Enclosed methods (circle):	Tubes	Perimeter	Panels	Class I product	Fiber
Lasers & optics secured to table:					
Beam properly contained:					
Beam blocks (circle):	Secured				Loose
Other means (describe):					
Beam in line with workstations:					
Evidence of laser burns or cross hairs on walls:					
Reflections contained, specular as well as diffuse:					
Beams blocked from directly exiting open door or window:					
Beams required to leave table?					
Crosses walk way (controls in place):					
Describe:					
Passes into adjacent room/chamber					
Describe means and controls					
Non-essential materials out of beam path					
Upward directed beams:					
Blocked:					
Vertical labels used:					
Collecting optics used in room:					
Fiber optics in use (circle):	Bare		Jacketed (plastic, armor)		Totally enclosed system
Fiber ends labeled:					
Container for sharps:					
Container properly labeled:					
Fiber conduit labeled:					

Personnel factors

Laser eye exam by all laser personnel: _____

Laser safety training current (EHSS280): _____

OJI completed: _____

Correct laser protective eyewear available (OD & wavelength): _____

Proper storage, where: _____ outside use area _____ inside use area

Sufficient quantity on hand: _____

General condition of laser protective eyewear (circle): _____ Very good _____ Good _____ Fair _____ Damaged _____

OD & wavelength readable: _____

Observable cracks or scratches on lens: _____

Skin protection needed (circle): _____ Yes _____ No _____

Skin protection available (circle): _____ Yes _____ No _____

Lens in need of cleaning: _____

Process interaction

Are gases/vapors/fumes controlled? (circle): _____ Yes _____ No _____

Non-beam--electrical items _____

Optical tables grounded? _____

Commercial equipment? (circle): _____ All _____ Some home made _____

Associated non-beam concerns related to this work _____

List _____

Chemicals _____ Optic cleaning solvents: _____ 2nd containment: _____

This appendix is not informative appendix;
it is intended for information only.

Additional comments and notes:



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Form B3. Example of Laser Program Self-Evaluation Form

Introduction

The following audit form may be used by laser facility personnel to assess the adequacy of their laser safety program, as well as identify and correct any non-compliance issues with the applicable ANSI standards. This form is not intended to meet the needs of every facility; the auditor should be mindful of the facility's requirements, as well as federal, state and local regulations that may impact program commitments. The auditor should also include comments for suggested program improvements if any shortcomings are found.

Laser Safety Audit Report

- a) Management Oversight:
 - 1. Management support of laser safety program
 - 2. Laser Safety Committee (LSC)
 - 3. Laser Safety Officer (LSO)
 - 4. Authorized users
 - 5. Corrective action procedures
 - 6. Previous audit findings
- b) Program Changes:
 - 1. Program and procedural changes approved and implemented since previous audit
- c) Facilities (Indoor and Outdoor):
 - 1. Laser use facilities
 - 2. Laser hazard control areas
 - 3. Non-beam hazard controls
- d) Equipment and Instrumentation:
 - 1. Operable and calibrated assessment equipment
 - 2. Procedures
- e) Laser Use, Control, and Transfer:
 - 1. Laser, project, facility, and user authorization procedures
 - 2. Control against unauthorized laser use
 - 3. Spectator viewing
 - 4. On-site and off-site laser transfer
 - 5. Export controls
- f) Laser Area Assessments:
 - 1. Initial assessments and periodic surveys

2. Inventories
3. Non-reportable events and near-misses
- g) Training and Instructions to Workers:
 1. Training and retraining requirements and documentation
 2. Interviews and observations of routine work
 3. Staff knowledge of routine activities
 4. Emergency situations
 5. Oversight measures by authorized users
- h) Decommissioning and Associated Hazardous Material Disposal:
 1. Laser decommissioning
 2. Facility decommissioning
 3. Hazardous material disposal
- i) Notification and Reports:
 1. Theft or loss
 2. Incidents and overexposures
 3. Notification of changes to laser inventory, project use, facility, or authorized users to the LSO
- j) Posting and Labeling:
 1. Posting of NHZs
 2. Laser and laser system labeling
 3. Labeling of protective equipment
 4. Labeling of non-beam hazards
- k) Independent and Confirmatory Measurements:
 1. Laser beam surveys
 2. Laser reclassifications
 3. Facility-made laser certification
- l) CDRH Variance Reviews
- m) Audit Findings

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- U.S. Army Regulation 11-9, the Army Radiation Safety Program, Headquarters, Department of the Army, Washington DC, 28 May 1999.

Appendix C

Frequently Reported Incidents

Review of reported incidents has demonstrated that accidental eye and skin exposures to laser radiation and accidents related to the non-beam hazards of a laser or laser system, are most often associated with conditions described below.

- a) Unanticipated eye exposure during alignment
- b) Misaligned optics and upwardly directed beams
- c) Available laser protective eyewear not used
- d) Equipment malfunction
- e) Improper methods of handling high voltage
- f) Intentional exposure of unprotected personnel
- g) Operators unfamiliar with laser equipment
- h) Lack of protection for non-beam hazards
- i) Improper restoration of equipment following service
- j) Laser protective eyewear worn not appropriate for laser in use
- k) Unanticipated eye/skin exposure during laser usage
- l) Inhalation of LGAC and/or viewing laser generated plasmas
- m) Fires resulting from the ignition of materials
- n) Eye or skin injury of photochemical origin
- o) Failure to follow SOPs
- p) Introduction of foreign materials (pages of loose paper, paper clips, falling items or objects)
- q) Modification of the beam path

Appendix D

Guide for Organization and Implementation of Employee Laser Safety Training Programs

The extent to which the various parts of the following guide are applicable to a specific organization depends on the magnitude of the potential laser hazards within that organization. However, it is essential that each laser safety program include sufficient training of personnel in laser safety.

D1. Employee Training

D1.1 General. Training may be provided to users of Class 1M, Class 2, Class 2M or Class 3R lasers. Laser safety training must be provided to users of Class 3B or Class 4 lasers. Training programs may be developed by the employer organization. Short courses and other training programs on laser safety are also commercially available.

Employers should consider awareness level training for employees operating laser systems that enclose higher power lasers as well as laser awareness training to staff who work in areas with posted laser warning signs or where Class 1 or higher laser systems are in use (testing areas, fabrication areas, biological laboratories). This training may be used to communicate the safety or potential hazards under conditions other than those of normal operations. An explanation of the differences of potential hazards between the classes of lasers is beneficial to the user and adjacent staff.

The LSO determines what, if any, training is commensurate with the laser hazards accessible at the employer's facility.

D1.2 Laser Safety Training Program Topics. Topics for a laser safety training program for Class 3B and Class 4 laser use may include, but are not necessarily limited to, the following:

- a) For user personnel routinely working with or potentially exposed to Class 3B or Class 4 laser radiation:
 1. Fundamentals of laser operation (e.g., physical principles, construction). This topic should be considered optional based on the background of the laser users.
 2. Bioeffects of laser radiation on the eye and skin
 3. Significance of specular and diffuse reflections
 4. Non-beam hazards of lasers
 5. Laser and laser system classifications
 6. Control measures
 7. Overall responsibilities of management and employee
 8. Medical surveillance practices (if applicable)

- b) For the LSO or other individuals responsible for the laser safety program, evaluation of hazards, and implementation of control measures, or any others if directed by management to obtain a thorough knowledge of laser safety:
 - 1. The topics in D1.2 (a)
 - 2. Laser terminology
 - 3. Types of lasers, wavelengths, pulse shapes, modes, power/energy
 - 4. Basic radiometric units and measurement devices
 - 5. MPEs
 - 6. Laser hazard evaluations and other calculations

D1.3 On-the-Job Training (OJT). For Class 3B and Class 4 laser users, an actual hazard orientation for the laser systems and work area is critical to laser and general safety. An individual familiar with the work should conduct this training. Laser users should not be allowed to work unsupervised until OJT is completed. OJT may consist of two levels: one for safety awareness (e.g., demonstration of which eyewear to wear, how to check for stray beams), another for demonstrating how equipment works and evaluating the ability of the user to understand and follow procedures. This can be accomplished on a task by task basis.

D1.4 Class 2 and Class 2M Awareness Training. For optional Class 2 and Class 2M training, simple, brief programs may be developed that are designed for easy implementation by persons other than LSOs or training instructors, such as first line supervisors. Potential topics include:

- a) Simple explanation of a laser
- b) Compare the differences between laser light and ordinary light
- c) Explain a Class 2 laser with the concept that it is harmless for exposure duration less than the human aversion response time of 0.25 s
- d) Explain the differences between a Class 2 and a Class 2M laser
- e) Provide statement cautioning against intentionally overcoming the human aversion response and staring into a Class 2 or Class 2M laser beam
- f) General explanation of the differences in the various laser classifications

D1.5 Class 1M and Class 3R Awareness Training. For optional Class 1M and Class 3R training, simple brief programs may be developed that are designed for easy implementation by persons other than LSOs or training instructors, such as first line supervisors. Potential topics include:

- a) Simple explanation of a laser
- b) Compare the differences between laser light and ordinary light
- c) Describe the nature of near IR laser beams where applicable
- d) Explanation of Class 1M and 3R lasers, and the relative potential hazard of each
- e) Explanation of the potential for collecting and focusing optics to increase the hazard

D1.6 Laser Pointer Awareness. If laser pointer awareness education is determined to be desirable, suggested topics can include:

- a) Simple explanation of a laser
- b) Compare the differences between laser light and ordinary light
- c) Precautions for use
- d) Effects of exposures
- e) Misuse/FDA warning on misuse of pointers
- f) FDA limit of 5 mW
- g) Local ordinance limitations

D2. References

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US Code of Federal Regulations: 29CFR Part 1910.132, General Requirements for Protective Equipment.

US Code of Federal Regulations: 29CFR Part 1910.133, Eye and Face Protection.

US Code of Federal Regulations: 29CFR Part 1910.134, Respiratory Protection.

US Code of Federal Regulations: 29CFR Part 1910.147, Control of Hazardous Energy (Lockout/Tagout).

US Code of Federal Regulations: 29CFR Part 1910.331, Safety Related Work Practices, Training.

US Code of Federal Regulations: 29CFR Part 1910.1200, Hazard Communication (Right to Know).

US Code of Federal Regulations: 29CFR Part 1910.1405, Occupational Exposures to Hazardous Chemicals in Laboratories.

US Code of Federal Regulations: 29CFR Part 1926.54, Nonionizing Radiation.

US Code of Federal Regulations: 29CFR Part 1926.102, Eye and Face Protection.

Appendix E

Medical Examinations

E1. Medical Referral Following Suspected or Known Laser Injury

Any employee with an actual or suspected laser-induced injury should be evaluated by a medical professional as soon as possible after the exposure. Referral for medical examinations should be consistent with the medical symptoms and the anticipated biological effect based upon the laser system in use at the time of the incident (see Appendix G). For laser-induced injury to the retina, the medical evaluation should be performed by an ophthalmologist. Employees with skin injuries should be seen by a dermatologist. (See Appendix E of ANSI Z136.1 for examination protocols.)

E2. Skin Examination

Not required for pre-placement examinations of laser workers; however, it is suggested for employees with history of photosensitivity or working with UV lasers. Any previous dermatological abnormalities and family history should be reviewed. Any current complaints concerned with the skin are noted as well as the history of medication usage, particularly concentrating on those drugs that are potentially photosensitizing.

Further examination should be based on the type of laser radiation, above the appropriate MPEs, present in the individual's work environment.

E3. Termination Medical Examinations

The primary purpose of termination examinations is for the legal protection of the employer against unwarranted claims for damage that might occur after an employee leaves a particular job. The decision on whether to offer or require such examinations is left to individual employers.

E4. References

Department of the Army Field Manual 8-50. "Prevention and Medical Management of Laser Injuries," Headquarters, Department of the Army, Washington, D.C. August 1990.
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Appendix F

Non-Beam Hazards

F1. Physical Agents

F1.1 Electrical Hazards. Electrical equipment in general presents these potential hazards: shock, electrocution, resistive heating, arc flash, and ignition of flammable materials.

F1.1.1 Shock and Electrocution. Electric shock and electrocution result from excessive electric current in tissue. Shock may include minor “tingle,” startle reactions, and serious personal injury. At 60 hertz, current as low as 5 milliamperes (mA) can cause a painful shock; current as low as 30 mA may result in electrocution.

In addition to the magnitude of the current, the path through the body is critical, especially if the path is through the heart. This may result in ventricular fibrillation where the lower chambers of the heart beat erratically. Death may result if not treated immediately. Other organs and systems at risk of injury include the nervous system, skin, kidneys, liver and musculature.

Exposures occur from contact with or arcing from energized electrical conductors contained in laser control systems, power supplies, and other devices. Exposures can occur during laser set up or installation, maintenance, modification, and service, where equipment protective covers are often removed to allow access to active components as required for those activities. Those exposed can be equipment installers, laser users, technicians, and uninformed members of the public.

F1.1.2 Resistive Heating. Heating of a conductor due to electric current flow increases with the conductor's resistance. Unchecked and increasing resistive heating can produce excessive heat build-up and potentially damage/corrode system components. While laser system designers generally provide sufficient cooling for routine operations, equipment should be regularly checked for excessive resistive heating symptoms such as component warping, discoloration, or corrosion, and repaired as needed.

F1.1.3 Electric Spark Ignition of Flammable Materials. Equipment malfunctions can lead to electrical fires. In addition, electrical sparks can serve as an ignition source in the presence of a flammable vapor.

F1.1.4 Arc Flash. An electrical arcing fault can produce an arc flash that includes intense radiant energy, high temperature air, high-pressure wave, and high-velocity shrapnel from the electrical apparatus and housing. Causes of arc flash are human error while working on energized electrical equipment and equipment malfunction (old, poorly maintained, poorly designed). Workers involved in arc flash may incur serious injury or death. Estimates are as high as 5-to-10 arc-flash incidents per day that result in serious injury in North America.

F1.1.5 Electrical Hazard Control Measures. Laser devices, systems, and those who work with them are subject to the electrical safety requirements of United States Department of Labor, Occupational Safety and Health Administration (OSHA), the National Electrical Code (NEPA 70E, Article 330), and related state and local laws and regulations. These requirements govern equipment connection to the electrical utilization system, electrical

protection parameters, and specific safety training. These requirements must be observed with all laser installations. The potential for arc flash must be evaluated and controlled per requirements in NFPA 70E (CSA Z462 in Canada). Fire extinguishers designed for electrical fires should be used with laser systems. An "emergency stop" switch can serve to eliminate or minimize electrical hazards in an emergency.

F1.2 Collateral and Plasma Radiation. Collateral radiation is radiation other than that associated with the primary laser beam and may be produced by system components such as power supplies, discharge lamps and plasma tubes. Such radiation may take the form of x-rays, UV, visible, infrared (IR) and radio-frequency radiation (RFR) as well as extremely low frequency (ELF) electric and magnetic fields.

Plasma radiation is generated when a high-fluence laser beam interacts with matter, typically metals. Such interactions can produce gamma-rays, x-rays, UV, visible, IR and RFR.

F1.2.1 Collateral Radiation. This section summarizes some potential sources of collateral radiation. For evaluation of potential exposure and recommendations for suitable controls, the LSO should consult a health physicist or industrial hygienist.

F1.2.1.1 Ionizing Radiation. X-rays may be generated by electronic components of the laser system, e.g., high-voltage vacuum tubes (usually greater than 15 kV) and from laser-metal induced plasmas. The characteristics and intensity of x-rays emanating from laser power supplies and components therein should be investigated.

F1.2.1.2 Ultraviolet (UV) and Visible Radiation. UV and visible radiation may be emitted from laser discharge tubes and pump lamps. The presence of UV radiation at short wavelengths, generally less than 220 nm, may produce ozone. Exposures should be evaluated against a recognized exposure guideline such as the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs) for UV and non-coherent optical radiation.

F1.2.1.3 Radio Frequency Radiation (RFR). Some lasers contain radio frequency (RF) excited components (e.g., plasma tubes and Q-switches) and RF generators may be used as the energy pump for some molecular lasers (e.g., CO₂ lasers). Evaluations of the potential for overexposure should use a recognized standard such as IEEE C95.1.

F1.2.1.4 Extremely Low Frequency (ELF) Fields. Power supplies and other electrical equipment associated with some lasers are capable of generating intense electric and magnetic ELF fields at the power frequency (50 or 60 Hz) and harmonics of the power frequency. Evaluation of potential exposures should use a recognized standard such as IEEE C95.6. If interference with implanted medical electronic devices is a concern, consult with the manufacturer of the device for specific guidance.

F1.2.1.5 Static Magnetic Fields. Faraday rotators, ion gauges, super conducting magnets and other devices that may be associated with laser work can produce intense magnetic fields that may attract loose ferromagnetic materials such as paper clips, tools, carts, trays, and compressed gas cylinders. These objects may accelerate toward the magnet with the potential to cause injury and facility damage. Evaluation of potential exposures should use recognized guidelines such as the 2009 ICNIRP limits for static magnetic fields or the ACGIH TLVs.

F1.2.2 Plasma Radiation. Plasma emissions created during laser-material interaction processes may contain both nonionizing radiation such as UV, visible and IR radiation, and

ionizing radiation such as gamma-rays, x-rays, and particle beams. Additional radiation such as neutrons and high-energy x-rays can be emitted by target materials exposed to high irradiance beam interactions. For laser-material interactions that are likely to produce ionizing radiation, a health physicist or radiation safety officer (RSO) should be consulted.

F1.2.2.1 X- and Gamma-Radiation. High-intensity laser beam interactions may generate plasmas that consequently produce ionizing radiation. This conversion process is wavelength, pulse-length, and intensity dependent. In general, this typically occurs when pulsed laser beams are focused on a target with peak irradiance of the order of 10^{12} W·cm⁻² or higher.

F1.2.2.2 Particle Beams. Laser interactions with materials can generate electric fields that are a million times stronger (10^{12} V·m⁻¹) than that which conventional accelerators can produce. At very high laser irradiances (e.g., $> 10^{18}$ W·cm⁻²), these fields accelerate a high fluence of energetic, charged particles, such as ions and electrons, at energies of millions of electronvolts (MeV) and billions of electronvolts, (GeV).

Similarly, electron beams can be generated from MeV to 10 GeV energies at irradiances near 10^{15} W·cm⁻². Strong electron beams at laser irradiances greater than 10^{17} W·cm⁻² generate electromagnetic pulses when they interact with vacuum chamber walls or instrumentation. Electromagnetic pulses can damage equipment including safety monitoring equipment and control hardware.

F1.2.2.3 Radioactivation. Particle beams produced as a result of laser irradiation of materials at high peak irradiances ($> 10^{17}$ W·cm⁻²) have been shown to induce radioactivation of materials in the walls and instruments within vacuum chambers. When operating at high levels of peak irradiance, radiation monitoring of vacuum hardware by a health physicist or RSO is recommended.

F1.2.2.4 UV, Visible and IR (Non-coherent Optical) Radiation. Sufficient UV and short-wavelength visible radiation (180 to 550 nm) can be produced by laser-matter interactions to raise concern about long-term viewing without protection. The types of lasers that may produce significant levels of non-coherent optical plasma radiation are the CO₂, Nd:YAG and other near-IR lasers such as fiber and diode lasers. Events where the beam is directed onto the surface of the target, such as welding, have been shown to produce higher plasma radiation levels than events where the beam may be shielded by the target, such as cutting.

F1.2.3 Control Measures for Non-beam Radiation. Consult a health physicist or RSO for guidance on evaluation and controls, and to ensure compliance with all applicable federal and state legal requirements.

Enclose or isolate the source. Ensure that maintenance or service procedures and work practices do not place workers at risk of over exposure.

Use local exhaust ventilation to control ozone, as applicable. UV photocuring devices should be operated with caution to preclude exposure to UV radiation and viewing the light source. Protective filter lenses or faceshields of the appropriate attenuation should be worn to protect the eye and skin of the face from UV radiation and visible light, as applicable.

Commercially-available laser systems use RF guards, conductive gaskets, numerous fasteners, and grounding to control RF emissions. In some cases, an exposure evaluation may demonstrate the necessity to establish a RF safety program (see IEEE C95.7). If RF warning

signs and labels are necessary, these should follow the specifications found IEEE C95.2, ANSI Z535.2, and ANSI Z535.4.

ELF electric fields may be shielded, but shielding of magnetic fields may be complex. Active and passive field cancellation technology may also be used, as well as isolation of the source from the worker by distance. Warning signs should be posted to inform workers of restrictions for wearers of medical electronic devices.

For static magnetic fields, evaluation may be used to determine the region of space where the magnetic-flux density is 5 gauss (G). Certain workers may be restricted from entry beyond the 5 G line, such as those with implanted medical electronic devices. Other items that may be restricted to the 5-G line include ferromagnetic materials and magnetizable media. Warning signs should be posted to inform workers of such restrictions.

F1.3 Fire Hazards. Class 4 laser beams represent a fire hazard as the source of ignition. Organic solvents used with dye lasers may be combustible. Class 4 laser beams may ignite enclosure, building, and target materials, as well as system components (e.g., unprotected wire insulation and plastic tubing). Fire potential occurs with irradiances exceeding 10 W cm^{-2} or beam powers exceeding 0.5 W. The laser most often involved in fires is the Class 4 CO_2 laser. Under some situations where flammable compounds or substances exist, it is possible that fires can be initiated by Class 3B lasers. The LSO should encourage the use of flame retardant materials wherever applicable.

NOTE—The National Fire Protection Agency (NFPA) states that for CW lasers 0.5 W cm^{-2} is a possible ignition hazard.

F1.3.1 Control Measures. Users can refer to NFPA Code 115 for information on controlling laser induced fires. Opaque laser barriers, e.g., curtains, can be used to block the laser beam during certain operations (see Section 4.6). While these barriers can be designed to offer a range of protection, they normally cannot withstand high irradiance levels for more than a few seconds without some damage, e.g., production of smoke, open fire, or penetration. Users of commercially available laser barriers should obtain appropriate fire prevention information from the manufacturer. A fire extinguisher appropriately rated for possible fire types, including electrical fires must be located in the work place. Consideration must be given to the type of fire extinguisher used and the impact on optics. Carbon dioxide or other non-powder base extinguishers are suggested.

F1.4 Explosion Hazards. Explosion hazards exist with certain system components (e.g., high-pressure arc lamps, filament lamps, capacitor banks, optical components), associated equipment (e.g., components of local exhaust ventilation systems), and target materials. There have been reports of explosions involving dirty zinc selenide lenses and by ignition of dust that has collected in ventilation systems serving laser processes.

F1.4.1 Control Measures. Laser equipment should be enclosed in housings that can withstand the maximum explosive pressure resulting from component disintegration. The laser target and elements of the optical train that may shatter during laser operation should also be enclosed or equivalently protected to prevent injury to operators and observers. The potential for damage to optics and ventilation systems can be greatly minimized by good maintenance practices. Explosive reactions of chemical laser reactants or other laser gases may be a concern in some cases.

F1.5 Mechanical Hazards Associated with Robotics. In many industrial applications lasers are employed in conjunction with robots. Robots can punch holes in protective housings, damage beam delivery system, and cause a laser beam to be aimed at operators or enclosures. In addition to such hazards, the mechanical safety of the robot installation must be carefully considered. Accidents have occurred where a worker has been pinned between a robot and a confining object ("pinch effect").

F1.5.1 Control Measures. The installation should conform to recommendations contained in ANSI/RIA R15.06. Consideration should be given to hard and soft stops to control the angular extent of laser beam emissions into the workplace to protect workers and the facility.

F1.6 Noise. Workplace noise may produce a spectrum of effects including temporary and permanent threshold shift in hearing, startle responses, and speech interference. Levels from certain lasers (e.g., pulsed excimer lasers) or system components (e.g., assist gas nozzles), and the work environment, may be of such intensity that noise control may be necessary.

F1.6.1 Control Measures. Consult the US Department of Labor, Occupational Safety and Health Administration Regulations and the ACGIH TLVs.

F1.7 Glass Particle Hazards. Small lengths or particles of optical fiber material may pose a risk of irritation or injury, particularly when cleaving fibers during splicing or connectorizing operations. Personnel should not eat in a fiber cleaving area.

F1.7.1 Control Measures. Personnel should be warned of glass particle hazards. The use of protective guards or shields should be considered, especially during cleaving operations. Discarded pieces of fiber should be collected in a suitable container to avoid subsequent embedding in clothing or skin. When a container is not available the pieces should be wrapped in tape and placed in a plastic bag.

F2. Chemical Agents

These include LGAC, compressed gases, dyes and solvents, cryogenic liquids, and nanomaterials.

The LSO should ensure that industrial hygiene aspects associated with exposure to chemical agents are addressed and that appropriate control measures are effected in accordance with applicable federal, state, local and institutional requirements.

F2.1 LGAC. Air contaminants may be generated when certain Class 3B and Class 4 laser beams interact with matter. The quantity, composition, and chemical complexity of the LGAC depend greatly upon the target material, cover gas, and the beam irradiance.

When the target irradiance reaches approximately 10^7 W/cm^2 target materials including plastics, composites, metals, and tissues may liberate carcinogenic, toxic and/or noxious LGAC. (See Table F1a and Table F1b in Appendix F of ANSI Z136.1-2007).

It is difficult to predict what LGAC may be released in any given interaction situation, and a wide variety of contaminants can be produced with many types of lasers. LGAC may be particles, aerosols, gases or vapors and may include new compounds.

The quantity of LGAC may be greater for lasers that have most of their energy absorbed at the surface of the material.

Exposure criteria can be found in OSHA 29 CFR 1910 Subpart Z – Toxic and Hazardous Substances, the ACGIH *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, CSA Z305.13-09 and Material Safety Data Sheets (MSDS) from the manufacturer of the laser system, laser machine or target material. After characterization of the contaminant, it may be necessary for the LSO to effect appropriate control measures.

F2.1.2 Control Measures. Engineering control measures should be given priority for controlling hazards. Engineering control measures include isolation, local exhaust ventilation and the substitution of substances that produce less toxic by-products (See Table F1c in Appendix F of ANSI Z136.1-2007).

Respiratory protection may be used to control brief exposures, or as an interim control measure until other engineering or administrative controls are implemented. If respiratory protection is utilized, the program should comply with OSHA 29 CFR 1910.134.

F2.2 Compressed Gases. Compressed gases may be used as the lasing medium, assist gas, cover gas or as part of the experiment. Depending on the particular gas, compressed gases may present both physical and chemical hazards.

All compressed gases present a hazard due to the potential energy from the compression of the gas. Gases may also be toxic, corrosive, flammable or oxidizers. Hazardous gases used in lasers and laser applications include chlorine, fluorine, hydrogen chloride and hydrogen fluoride.

Hazard information can be found in MSDS provided by the manufacturer or distributor of the gas and in Compressed Gas Association standards and recommendations.

F2.2.2 Control Measures. A SOP for the safe use, handling and storage of compressed gases should be in effect.

Engineering control measures for hazardous gases may include exhausted gas cabinets armed with alarm sensors to indicate potential leakage conditions.

F2.3 Laser Dyes and Solvents. The lasing medium for dye lasers consists of fluorescent organic dyes dissolved in organic solvents. The toxicological properties of many laser dyes have not been fully investigated, but many dyes are members of chemical families that contain toxic chemicals. Organic solvents used for laser dyes are often flammable and may be toxic by inhalation or skin absorption. Exposure to laser dyes and solvents may occur when preparing and changing dyes and operating dye lasers.

Exposure criteria can be found in OSHA standard 29 CFR 1910 Subpart Z – Toxic and Hazardous Substances, the ACGIH *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, and MSDS from the manufacturer of the dyes and solvents.

F2.3.2 Control Measures. Laser dyes should be prepared under a laboratory fume hood.

Flammable liquid use and storage should be in conformance with the provisions of NFPA 30, NFPA 45, and NEC Article 500.

Dye pumps and reservoirs should be placed in secondary containment vessels to minimize leakage and spills in conformance with NFPA 115.

F2.4 Cryogenic Liquids. Cryogenic liquids may be used to cool the laser crystal and associated equipment. The primary hazards of cryogenic liquids are extreme cold and asphyxiation. Cryogenic liquids can burn the skin and eyes. Vaporization of cryogenic liquids can displace oxygen, and in small, poorly ventilated areas, can create an oxygen deficient atmosphere.

Hazard information can be found in Compressed Gas Association standards and recommendations.

F2.4.2 Control Measures. These include PPE (gloves and eye protection), insulated transfer lines, phase separators and ventilation. Oxygen sensors should be installed in storage areas.

F2.5 Nanoparticles. Nanoparticles, which are intentionally produced or engineered nanomaterials, are small particles often defined as having a dimension between 1 and 100 nm. Nanoscale aerosols (nanoaerosols) that are generated from naturally-occurring and man-made processes are called ultrafine particles.

Ultrafine particles may be a by-product of laser-material processing applications. As an air contaminant, these particles may agglomerate (i.e., clump together into aggregates), which changes their aerodynamic properties. Individual ultrafine particles, as airborne contaminants, do not settle from the air but remain airborne—behaving much like gas molecules—and are not easily filtered. Agglomerates of ultrafine particles may be more easily filtered.

In addition to producing ultrafine particles as an airborne contaminant, lasers are used in the intentional production of nanoparticles. This may involve ablation via ultrashort laser pulses or pulsed-laser deposition (PLD). As with ultrafine particles, laser-generated nanomaterials also agglomerate.

There are a number of issues associated with nanoscale materials. They have a greater surface area to mass ratio than other particulates, can be more reactive and have more absorption capacity. The physiological and chemical impact on biological processes is not well understood. There are reports of entry through intact skin, translocation to the brain via the olfactory nerve, and passage through the cell membrane.

F2.5.1 Control Measures. Engineering methods should be used to control contaminants near the point of generation. Standard and specialized filter media have been demonstrated to control particles smaller than 100 nm. In general, studies have demonstrated that filtration efficiency increases with decreasing particle size within the ultrafine particle region. High efficiency particulate air (HEPA) filters are tested at the most penetrating particle size, which is often cited as 0.3 μm diameter particles. The test particle must be collected with a minimum efficiency of 99.97%. Smaller and larger particles will be collected with greater efficiency than the most penetrating particle size.

With respect to housekeeping, the workplace should be cleaned with a HEPA-filtered vacuum cleaner or by wet methods to minimize the re-entrainment of nanoscale particles into the air.

F3. Biological Agents

These include LGAC and infectious materials. LGAC may be generated when high power laser beams interact with tissue. Infectious materials, such as bacterial and viral organisms, may survive beam irradiation and become airborne. For more information, see ANSI Z136.3. The institution's biological safety officer should be consulted for advice and to be sure control measures meet applicable biosafety requirements.

F4. Human Factors

F4.1 General. Ergonomic and human factor issues include poor work station layout, poor illumination, repetitive motion, material handling, and work patterns; each should be recognized, evaluated and controlled. While ergonomics and human factors are sometimes used synonymously, ergonomics focuses on how work affects people and includes consideration of physiological responses to demanding work, environmental stressors (e.g., heat, noise, illumination), and complex visual monitoring and assembly tasks.

Conversely, the human factors emphasis is on reducing the potential for human error by optimizing the machine-human interface. The field of human factors focuses on people's behavior and capability (size and strength) relative to the design of product and equipment.

The LSO should ensure the application of ergonomics and human factors principles to laser system design(s) so that potential hazards are identified. While the LSO may not possess sufficient knowledge to effect the full evaluation and control of potentially hazardous circumstances related to ergonomics and human factors, the LSO needs to be able to recognize such circumstances for referral to others with the necessary expertise for appropriate follow up.

F4.2 Poor Work Station Layout. This can result in work space with spatial constraints that make it unsafe to work near or around laser-related mechanical or high voltage equipment (see National Electrical Code, Section 110-16). Even in the absence of such equipment, sufficient room must be provided for personnel to turn around and maneuver freely under both non-emergency and emergency conditions. A layout that does not provide for adequate separation and/or isolation of laser-related laboratory work from other work areas can result in unnecessary potential exposure of non-laser-using personnel to laser-related hazards. Operation of more than one type of laser (i.e., multiple laser wavelengths) in the same work space may increase the challenge of providing laser eye protection and the potential for eye injury (i.e., probability of incorrect laser eye protection being worn may be increased).

F4.2.1 Control Measures. Wires, cables, and other utility lines supporting lasers or other laser laboratory equipment operation should be routed so they do not pose tripping or entanglement hazards for laboratory personnel. When wires, cables, lines, or hoses must be run across floor walkways, cable bridges should be placed over these items to protect them and reduce the tripping hazard that they pose. Because of their combustibility, wooden bridges should be avoided. While extremely sturdy, metal bridges sometimes require grounding. Plastic bridges are also sturdy, do not require grounding and can be linked together to fully bridge an aisle or other walking surface. Cable trays should be used to protect and isolate electrical wires and cables and separate them from other incompatible utility lines (e.g., water lines). Available health and safety-related design guidance for laboratories, including those using lasers, is available and should be consulted as part of the

laser laboratory layout design development process. Those involved in this process need to consider the design and location of work and optical benches and tables, hand-operated controls, computer workstation-based controls, warning lights, warning signs/labels, emergency stop controls, equipment maintenance access points, lighting, and enclosures/shielding.

F4.3 Poor Illumination. This may occur when a laboratory is darkened to prevent stray light from entering a detection system used in experiments employing lasers.

F4.3.1 Control Measures. When low light levels are required, mechanisms must be employed to direct laboratory occupants to exits and emergency equipment. Such mechanisms may include luminescent strips or arrows and/or lighting with wavelengths not interfering with detection system(s) in use. Recommendations for illuminance levels in laboratories should be followed.

F4.4 Repetitive Motion or Static Posture. The probability of injury increases for personnel whenever they become engaged in repetitive motions involving awkward posture (e.g., unique arm, hand, wrist and/or trunk deviations), excessive force, and/or extreme frequency/long duration. Laser systems requiring the use of microscopes may impose static posture stress on their users. Neck, back, forearm, wrist, and visual discomfort due to such stress have been reported in various studies.

F4.4.1 Control Measures. Recommendations for minimizing/correcting those microscope workstation design deficiencies contributing to static posture stress symptoms are available and should be implemented.

F4.5 Material Handling. Material handling can result in significant injury when performed improperly. Lower back strains and sprains are the most common injury associated with manual material handling.

F4.5.2 Control Measures. Manual material handling is among the most frequent and severe causes of injury. Therefore, workplace tasks that require manual lifting and lowering of materials should be minimized. When objects are too heavy (exceeds 35 lbs. [16 kg.]) and/or too bulky for a single person to lift, mechanical lifting aids or assistance from others need to be employed. Material handling and lifting aids include: special purpose carts, hoists, forklift trucks, and pallet jacks.

F4.6 Work Patterns. There is some evidence indicating that swing and third shift work patterns can affect worker alertness and that extended or excessive work hours can also adversely affect safety compliance. Fatigue is a common cause, or at least a contributing factor, in all types of accidents, including those involving lasers. Many of the reported laser accidents have occurred after normal work hours due in part to fatigue.

F4.6.1 Control Measures. Each organization should have a work scheduling policy that should be communicated to all employees, particularly those working with hazardous equipment such as higher power lasers. This and other fatigue prevention and reduction guidelines are available.

F5. References

- ACGIH: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices.
- ANSI/RIA R15.06 Standard for Industrial Robots and Robot Systems-Safety Requirements.
- ANSI Z136.1-2007, American National Standard for Safe Use of Lasers.
- ANSI Z136.3, American National Standard for Safe Use of Lasers in Health Care.
- ANSI Z535.2, American National Standard for Environmental and Facility Safety Signs.
- ANSI Z535.4, American National Standard for Product Safety Signs and Labels.
- CSA Z305.13-09, Plume Scavenging in Surgical, Diagnostic, Therapeutic, and Aesthetic Settings.
- IEEE C95.1, IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.
- IEEE C95.2, IEEE Standard for Radio-Frequency Energy and Current-Flow Symbols.
- IEEE C95.6, IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0 to 3 kHz.
- IEEE C95.7, IEEE Recommended Practice for Radio Frequency Safety Programs.
- NEC Article 500: Hazardous Locations.
- NEC Section 110-16: Flash Protection.
- NFPA 30: Flammable and Combustible Liquids Code.
- NFPA 45: Standard on Fire Protection for Laboratories Using Chemicals.
- NFPA 70E-2009, Article 330: Safety-Related Work Practices for Use of Lasers.
- NFPA 115: Standard for Laser Fire Protection.
- US Code of Federal Regulations: 29CFR Part 1910.134, Respiratory Protection.
- US Code of Federal Regulations: 29CFR Part 1910, Subpart Z, Toxic and Hazardous Substance.

Appendix G

Biological Effects of the Eye and Skin

G1. Minimal Biological Effects of Laser Radiation on the Eye

G1.1 General. The majority of the work in arriving at the MPEs discussed in Section 8 has been concerned with how to compare and weigh the data or damage thresholds from various laboratories. Some differences in standardization and calibration probably exists among different laboratories, which has introduced a certain spread among the data. Where regression lines were available, they indicate that a factor of 10 below the 50% damage level gave a negligible probability of damage. Whenever possible, these regression lines formed the basis for the level selected for any particular MPE. If the data indicated a steeper regression line, a factor less than 10 was used.

G1.2 Corneal Damage. For the purposes of this standard, a minimal corneal lesion is a small white area involving only the epithelium and whose surface is not elevated or swollen. It appears within 10 minutes after the exposure. Very little or no staining results from fluorescein application. A minimal lesion will heal within 48 hours without visible scarring.

G1.2.1 Infrared (1.4 to 1000 μm). Excessive infrared exposure causes a loss of transparency or produces a surface irregularity in the cornea. The MPE is well below the energy or power required to produce a minimal lesion. These observations are based on experiments with CO_2 lasers; extrapolation to wavelengths other than 10.6 μm must be made with care.

Damage results from heating resulting from absorption of the incident energy by tears and tissue water in the cornea. The absorption is diffuse and simple heat flow models appear to be valid. The identity of the sensitive material or protein in the cornea is not known. Although the exact critical temperature threshold value has not been found, it does not appear to be much above normal body temperature and there are many indications that it is a variable function of exposure duration.

G.1.2.2 Ultraviolet (180 to 400 nm). Excessive UV exposure produces photophobia accompanied by surface redness, tearing, conjunctival discharge, and corneal surface exfoliation and stromal haze. The MPE is well below the energy required to produce any of these changes. The adverse effects, which are usually delayed for several hours after the exposure, will occur within 24 hours.

Damage to the epithelium by absorption of UV light probably results from photochemical denaturation of proteins or other molecules in the cells. Some of the most important molecules are the deoxyribonucleic acids (DNA) and ribonucleic acids (RNA). The energy is probably absorbed by selective sensitive portion of single cells. The action of the UV radiation is photochemical rather than thermal, since the temperature rise calculated for experimental exposure is negligible.

G1.3 Retinal Damage (400 to 1400 nm). In the visible and near infrared region, 400 to 1400 nm, the MPE is well below the exposure required to produce a minimal (or threshold) lesion. For the purposes of this standard, a minimal retinal lesion is the smallest ophthalmoscopically visible change in the retina. This change is a small white patch

(apparently coagulation that occurs within 24 hours of the time of exposure). At threshold, the lesion is probably the result of local heating of the retina subsequent to absorption of the light and its conversion to heat by the melanin granules in the pigment epithelium. The most serious effects on vision will occur for damage in the central portion of the retina, the macula, and especially in the fovea.

Extended exposure lasting several minutes for a retinal image that is very small is difficult to accomplish, except by stabilized image optics. Thus, there exists no experimental data for long exposures and small spot sizes. However, accidental retinal exposures that combine long periods of time and small spot sizes are very unlikely.

G1.4 Other Ocular Damage. There are two transition zones between the corneal hazard and retinal hazard spectral regions. These are located at the wavelength bands separating the UV and visible regions and separating near infrared and infrared. The transition wavelengths are not precise, and in these transition regions, there may be both corneal and retinal damage. Damage to intermediate structures, such as the lens and iris, can also occur.

G1.5 References. The most important references are cited in this section below. They cover the major portion of the data used in deriving this standard. Several of the references are review articles; their bibliographies should be used as a source of additional references. The most comprehensive and up-to-date bibliography of laser effects on the eye and skin is *Laser Hazards Bibliography* published by the U.S. Army Environmental Hygiene Agency, Aberdeen Proving Ground, MD 21010-5422, and the latest version should be consulted.

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G2. Biological Effects of Laser Radiation on the Skin

G2.1 General. The large skin surface makes this body tissue readily available to accidental and repeated exposures to laser radiation. The biological significance of irradiation of the skin by lasers operating in the visible and infrared regions is considerably less than exposure of the eye, as skin damage is usually reparable or reversible. Effects may vary from a mild reddening (erythema) to blisters and charring. Depigmentation, ulceration, and scarring of the skin and damage to underlying organs may occur from extremely high-power laser radiation.

Outside of the UV region, latent and cumulative effects of laser radiation to the skin are not known at this time. The possibility of such effects occurring, however, should not be ignored in planning for personnel safety in laser installations.

Little or no data is available describing the reaction of skin exposed to laser radiation in the 200 to 400 nm spectral region, but chronic exposure to UV wavelengths in this range can have a carcinogenic action on skin as well as eliciting an erythematous response.

On the basis of studies with non-coherent UV radiation, exposure to wavelengths in the 250 to 320 nm spectral region are most injurious to skin. Exposure to the shorter (200 to 250 nm) and longer (320 to 400 nm) UV wavelengths is considered less harmful to normal human skin. The shorter wavelengths are absorbed in the outer dead layer of the epidermis (stratum corneum), and exposure to the longer wavelengths has a pigment darkening effect. However, the sensitivity of skin to the longer wavelengths may be increased by known or inadvertent usage of photosensitizers.

G2.2 References. The most comprehensive and up-to-date bibliography of laser effects on the eye and skin is *Laser Hazards Bibliography* published by the U.S. Army Environmental Hygiene Agency, Aberdeen Proving Ground, MD 21010-5422, and the latest version should be consulted.

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Appendix H

Laser Products Safety Rules

Certified laser products sold or manufactured in the United States should meet the CDRH laser product safety rules. Laser units sent off for technology transfer should also meet these regulations. Many ANSI Z136.1 engineering controls have been deleted from this standard due to the nature of R&D, but their importance in laser products cannot be understated. Following is the CDRH rules: obtained from the CDRH web site:
<http://www.fda.gov/AboutFDA/CentersOffices/CDRH/default.htm>

TITLE 21--FOOD AND DRUGS

CHAPTER I--FOOD AND DRUG ADMINISTRATION

DEPARTMENT OF HEALTH AND HUMAN SERVICES

SUBCHAPTER J--RADIOLOGICAL HEALTH

PART 1040 -- PERFORMANCE STANDARDS FOR LASER-EMITTING PRODUCTS

Sec. 1040.10 Laser products.

- a) *Applicability.* The provisions of this section and 1040.11, as amended, are applicable as specified to all laser products manufactured or assembled after August 1, 1976, except when:
- (1) Such a laser product is either sold to a manufacturer of an electronic product for use as a component (or replacement) in such electronic product, or
 - (2) Sold by or for a manufacturer of an electronic product for use as a component (or replacement) in such electronic product, provided that such laser product:
 - (i) Is accompanied by a general warning notice that adequate instructions for the safe installation of the laser product are provided in servicing information available from the complete laser product manufacturer under paragraph (h)(2)(ii) of this section, and should be followed.
 - (ii) Is labeled with a statement that it is designated for use solely as a component of such electronic product and therefore does not comply with the appropriate requirements of this section and 1040.11 for complete laser products, and
 - (iii) Is not a removable laser system as described in paragraph (c)(2) of this section; and
 - (3) The manufacturer of such a laser product, if manufactured after August 20, 1986:
 - (i) Registers, and provides a listing by type of such laser products manufactured that

includes the product name, model number and laser medium or emitted wavelength(s), and the name and address of the manufacturer. The manufacturer must submit the registration and listing to the Director, Food and Drug Administration, Office of Compliance, Document Mail Center – WO66-G609, 10903 New Hampshire Avenue, Silver Spring, MD 20993-0002.

- (ii) Maintains and allows access to any sales, shipping, or distribution records that identify the purchaser of such a laser product by name and address, the product by type, the number of units sold, and the date of sale (shipment). These records shall be maintained and made available as specified in 1002.31.

(b) *Definitions.* As used in this section and 1040.11, the following definitions apply:

- (1) *Accessible emission level* means the magnitude of accessible laser or collateral radiation of a specific wavelength and emission duration at a particular point as measured according to paragraph (e) of this section. Accessible laser or collateral radiation is radiation to which human access is possible, as defined in paragraphs (b) (12), (15), and (22) of this section.
- (2) *Accessible emission limit* means the maximum accessible emission level permitted within a particular class as set forth in paragraphs (c), (d), and (e) of this section.
- (3) *Aperture* means any opening in the protective housing or other enclosure of a laser product through which laser or collateral radiation is emitted, thereby allowing human access to such radiation.
- (4) *Aperture stop* means an opening serving to limit the size and to define the shape of the area over which radiation is measured.
- (5) *Class I laser product* means any laser product that does not permit access during the operation to levels of laser radiation in excess of the accessible emission limits contained in table I of paragraph (d) of this section.¹
- (6) *Class IIa laser product* means any laser product that permits human access during operation to levels of visible laser radiation in excess of the accessible emission limits contained in table I, but does not permit human access during operation to levels of laser radiation in excess of the accessible emission limits contained in table II-A of paragraph (d) of this section.²
- (7) *Class II laser product* means any laser product that permits human access during operation to levels of visible laser radiation in excess of the accessible emission limits contained in table II-A, but does not permit human access during operation to levels of laser radiation in excess of the accessible emission limits contained in table II of paragraph (d) of this section.³
- (8) *Class IIIa laser product* means any laser product that permits human access during operation to levels of visible laser radiation in excess of the accessible emission limits contained in table II, but does not permit human access during operation to levels of laser radiation in excess of the accessible emission limits contained in table III-A of paragraph (d) of this section.⁴

- (9) *Class IIIb laser product* means any laser product that permits human access during operation to levels of laser radiation in excess of the accessible emission limits of table III-A, but does not permit human access during operation to levels of laser radiation in excess of the accessible emission limits contained in table III-B of paragraph (d) of this section.⁵
- (10) *Class III laser product* means any Class IIIa or Class IIIb laser product.
- (11) *Class IV laser product* means any laser that permits human access during operation to levels of laser radiation in excess of the accessible emission limits contained in table III-B of paragraph (d) of this section.⁶
- (12) *Collateral radiation* means any electronic product radiation, except laser radiation, emitted by a laser product as a result of the operation of the laser(s) or any component of the laser product that is physically necessary for the operation of the laser(s).
- (13) *Demonstration laser product* means any laser product manufactured, designed, intended, or promoted for purposes of demonstration, entertainment, advertising display, or artistic composition. The term "demonstration laser product" does not apply to laser products which are not manufactured, designed, intended, or promoted for such purposes, even though they may be used for those purposes or are intended to demonstrate other applications.
- (14) *Emission duration* means the temporal duration of a pulse, a series of pulses, or continuous operation, expressed in seconds, during which human access to laser or collateral radiation could be permitted as a result of operation, maintenance, or service of a laser product.
- (15) *Human access* means the capacity to intercept laser or collateral radiation by any part of the human body. For laser products that contain Class IIIb or IV levels of laser radiation, "human access" also means access to laser radiation that can be reflected directly by any single introduced flat surface from the interior of the product through any opening in the protective housing of the product.
- (16) *Integrated radiance* means radiant energy per unit area of a radiating surface per unit solid angle of emission, expressed in joules per square centimeter per steradian ($\text{J}\cdot\text{cm}^{-2}\cdot\text{sr}^{-1}$).
- (17) *Invisible radiation* means laser or collateral radiation having wavelengths of equal to or greater than 180 nm but less than or equal to 400 nm or greater than 710 nm but less than or equal to 1.0×10^6 nm (1 millimeter).
- (18) *Irradiance* means the time-averaged radiant power incident on an element of a surface divided by the area of that element, expressed in watts per square centimeter ($\text{W}\cdot\text{cm}^{-2}$).
- (19) *Laser* means any device that can be made to produce or amplify electromagnetic radiation at wavelengths greater than 250 nm but less than or equal to 13,000 nm or, after August 20, 1986, at wavelengths equal to or greater than 180 nm but less than or equal to 1.0×10^6 nm primarily by the process of controlled stimulated emission.
- (20) *Laser energy source* means any device intended for use in conjunction with a laser to

supply energy for the operation of the laser. General energy sources such as electrical supply mains or batteries shall not be considered to constitute laser energy sources.

- (21) *Laser product* means any manufactured product or assemblage of components which constitutes, incorporates, or is intended to incorporate a laser or laser system. A laser or laser system that is intended for use as a component of an electronic product shall itself be considered a laser product.
- (22) *Laser radiation* means all electromagnetic radiation emitted by a laser product within the spectral range specified in paragraph (b)(19) of this section that is produced as a result of controlled stimulated emission or that is detectable with radiation so produced through the appropriate aperture stop and within the appropriate solid angle of acceptance, as specified in paragraph (e) of this section.
- (23) *Laser system* means a laser in combination with an appropriate laser energy source with or without additional incorporated components. See paragraph (c)(2) of this section for an explanation of the term "removable laser system."
- (24) *Maintenance* means performance of those adjustments or procedures specified in user information provided by the manufacturer with the laser product which are to be performed by the user for the purpose of assuring the intended performance of the product. It does not include operation or service as defined in paragraph (b) (27) and (38) of this section.
- (25) *Maximum output* means the maximum radiant power and, where applicable, the maximum radiant energy per pulse of accessible laser radiation emitted by a laser product during operation, as determined under paragraph (e) of this section.
- (26) *Medical laser product* means any laser product which is a medical device as defined in 21 U.S.C. 321(h) and is manufactured, designed, intended or promoted for in vivo laser irradiation of any part of the human body for the purpose of: (i) Diagnosis, surgery, or therapy; or (ii) relative positioning of the human body.
- (27) *Operation* means the performance of the laser product over the full range of its functions. It does not include maintenance or service as defined in paragraphs (b) (24) and (38) of this section.
- (28) *Protective housing* means those portions of a laser product which are designed to prevent human access to laser or collateral radiation in excess of the prescribed accessible emission limits under conditions specified in this section and in 1040.11.
- (29) *Pulse duration* means the time increment measured between the half-peak-power points at the leading and trailing edges of a pulse.
- (30) *Radiance* means time-averaged radiant power per unit area of a radiating surface per unit solid angle of emission, expressed in watts per square centimeter per steradian ($\text{W} \cdot \text{cm}^{-2} \cdot \text{sr}^{-1}$).
- (31) *Radiant energy* means energy emitted, transferred or received in the form of radiation, expressed in joules (J).

- (32) *Radiant exposure* means the radiant energy incident on an element of a surface divided by the area of the element, expressed in joules per square centimeter ($\text{J}\cdot\text{cm}^{-2}$)
 - (33) *Radiant power* means time-averaged power emitted, transferred or received in the form of radiation, expressed in watts (W).
 - (34) *Remote interlock connector* means an electrical connector which permits the connection of external remote interlocks.
 - (35) *Safety interlock* means a device associated with the protective housing of a laser product to prevent human access to excessive radiation in accordance with paragraph (f)(2) of this section.
 - (36) *Sampling interval* means the time interval during which the level of accessible laser or collateral radiation is sampled by a measurement process. The magnitude of the sampling interval in units of seconds is represented by the symbol (t).
 - (37) *Scanned laser radiation* means laser radiation having a time-varying direction, origin or pattern of propagation with respect to a stationary frame of reference.
 - (38) *Service* means the performance of those procedures or adjustments described in the manufacturer's service instructions which may affect any aspect of the product's performance for which this section and 1040.11 have applicable requirements. It does not include maintenance or operation as defined in paragraphs (b) (24) and (27) of this section.
 - (39) *Surveying, leveling, or alignment laser product* means a laser product manufactured, designed, intended or promoted for one or more of the following uses:
 - (i) Determining and delineating the form, extent, or position of a point, body, or area by taking angular measurement.
 - (ii) Positioning or adjusting parts in proper relation to one another.
 - (iii) Defining a plane, level, elevation, or straight line.
 - (40) *Visible radiation* means laser or collateral radiation having wavelengths of greater than 400 nm but less than or equal to 710 nm.
 - (41) *Warning logotype* means a logotype as illustrated in either figure 1 or figure 2 of paragraph (g) of this section.
 - (42) *Wavelength* means the propagation wavelength in air of electromagnetic radiation.
- (c) *Classification of laser products*
- (1) *All laser products.* Each laser product shall be classified in Class I, IIa, II, IIIa, IIIb, or IV in accordance with definitions set forth in paragraphs (b) (5) through (11) of this section. The product classification shall be based on the highest accessible emission level(s) of laser radiation to which human access is possible during operation in accordance with paragraphs (d), (e), and (f)(1) of this section.
 - (2) *Removable laser systems.* Any laser system that is incorporated into a laser product subject to the requirements of this section and that is capable, without modification, of

producing laser radiation when removed from such laser product, shall itself be considered a laser product and shall be separately subject to the applicable requirements in this subchapter for laser products of its class. It shall be classified on the basis of accessible emission of laser radiation when so removed.

- (d) *Accessible emission limits.* Accessible emission limits for laser radiation in each class are specified in tables I, II-A, II, III-A, and III-B of this paragraph. The factors, k_1 and k_2 vary with wavelength and emission duration. These factors are given in table IV of this paragraph, with selected numerical values in table V of this paragraph. Accessible emission limits for collateral radiation are specified in table VI of this paragraph.

Wavelength, nm	Emission duration, s	Class I		Class II		Class III-A		Class III-B	
		k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
400-700	≤ 0.25	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
400-700	0.25 < t ≤ 10	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5
400-700	t > 10	1.0	0.25	1.0	0.25	1.0	0.25	1.0	0.25
700-1400	≤ 0.25	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
700-1400	0.25 < t ≤ 10	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5
700-1400	t > 10	1.0	0.25	1.0	0.25	1.0	0.25	1.0	0.25
1400-14000	≤ 0.25	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1400-14000	0.25 < t ≤ 10	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5
1400-14000	t > 10	1.0	0.25	1.0	0.25	1.0	0.25	1.0	0.25

Table I. Accessible Emission Limits

TABLE 17A

Table 17A: Performance Data for the 1990-1991 School Year

CLASSIFICATION OF PERFORMANCE DATA FOR THE 1990-1991 SCHOOL YEAR			
PERCENTAGE OF STUDENTS ACHIEVING PROFICIENCY IN EACH OF THE FOLLOWING AREAS			
Subject	Reading	Math	Science
Elementary	75.00	75.00	75.00
High School	75.00	75.00	75.00

Notes: Percentages are based on the number of students who took the test. The number of students who took the test is 100 for each subject.

TABLE 17B

Table 17B: Performance Data for the 1990-1991 School Year

CLASSIFICATION OF PERFORMANCE DATA FOR THE 1990-1991 SCHOOL YEAR			
PERCENTAGE OF STUDENTS ACHIEVING PROFICIENCY IN EACH OF THE FOLLOWING AREAS			
Subject	Reading	Math	Science
Elementary	75.00	75.00	75.00
High School	75.00	75.00	75.00

Notes: Percentages are based on the number of students who took the test. The number of students who took the test is 100 for each subject.

Table 17: Performance Data for the 1990-1991 School Year

TABLE 11-10		UNITED STATES DEPARTMENT OF AGRICULTURE	
CATTLE AND CALVES		CATTLE AND CALVES	
CATTLE AND CALVES		CATTLE AND CALVES	
1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24
25	26	27	28
29	30	31	32
33	34	35	36
37	38	39	40
41	42	43	44
45	46	47	48
49	50	51	52
53	54	55	56
57	58	59	60
61	62	63	64
65	66	67	68
69	70	71	72
73	74	75	76
77	78	79	80
81	82	83	84
85	86	87	88
89	90	91	92
93	94	95	96
97	98	99	100

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1. The first step is to identify the problem or question that needs to be answered. This involves understanding the context and the specific requirements of the task.

1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32. 33. 34. 35. 36. 37. 38. 39. 40. 41. 42. 43. 44. 45. 46. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60. 61. 62. 63. 64. 65. 66. 67. 68. 69. 70. 71. 72. 73. 74. 75. 76. 77. 78. 79. 80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90. 91. 92. 93. 94. 95. 96. 97. 98. 99. 100. 101. 102. 103. 104. 105. 106. 107. 108. 109. 110. 111. 112. 113. 114. 115. 116. 117. 118. 119. 120. 121. 122. 123. 124. 125. 126. 127. 128. 129. 130. 131. 132. 133. 134. 135. 136. 137. 138. 139. 140. 141. 142. 143. 144. 145. 146. 147. 148. 149. 150. 151. 152. 153. 154. 155. 156. 157. 158. 159. 160. 161. 162. 163. 164. 165. 166. 167. 168. 169. 170. 171. 172. 173. 174. 175. 176. 177. 178. 179. 180. 181. 182. 183. 184. 185. 186. 187. 188. 189. 190. 191. 192. 193. 194. 195. 196. 197. 198. 199. 200. 201. 202. 203. 204. 205. 206. 207. 208. 209. 210. 211. 212. 213. 214. 215. 216. 217. 218. 219. 220. 221. 222. 223. 224. 225. 226. 227. 228. 229. 230. 231. 232. 233. 234. 235. 236. 237. 238. 239. 240. 241. 242. 243. 244. 245. 246. 247. 248. 249. 250. 251. 252. 253. 254. 255. 256. 257. 258. 259. 260. 261. 262. 263. 264. 265. 266. 267. 268. 269. 270. 271. 272. 273. 274. 275. 276. 277. 278. 279. 280. 281. 282. 283. 284. 285. 286. 287. 288. 289. 290. 291. 292. 293. 294. 295. 296. 297. 298. 299. 300. 301. 302. 303. 304. 305. 306. 307. 308. 309. 310. 311. 312. 313. 314. 315. 316. 317. 318. 319. 320. 321. 322. 323. 324. 325. 326. 327. 328. 329. 330. 331. 332. 333. 334. 335. 336. 337. 338. 339. 340. 341. 342. 343. 344. 345. 346. 347. 348. 349. 350. 351. 352. 353. 354. 355. 356. 357. 358. 359. 360. 361. 362. 363. 364. 365. 366. 367. 368. 369. 370. 371. 372. 373. 374. 375. 376. 377. 378. 379. 380. 381. 382. 383. 384. 385. 386. 387. 388. 389. 390. 391. 392. 393. 394. 395. 396. 397. 398. 399. 400. 401. 402. 403. 404. 405. 406. 407. 408. 409. 410. 411. 412. 413. 414. 415. 416. 417. 418. 419. 420. 421. 422. 423. 424. 425. 426. 427. 428. 429. 430. 431. 432. 433. 434. 435. 436. 437. 438. 439. 440. 441. 442. 443. 444. 445. 446. 447. 448. 449. 450. 451. 452. 453. 454. 455. 456. 457. 458. 459. 460. 461. 462. 463. 464. 465. 466. 467. 468. 469. 470. 471. 472. 473. 474. 475. 476. 477. 478. 479. 480. 481. 482. 483. 484. 485. 486. 487. 488. 489. 490. 491. 492. 493. 494. 495. 496. 497. 498. 499. 500. 501. 502. 503. 504. 505. 506. 507. 508. 509. 510. 511. 512. 513. 514. 515. 516. 517. 518. 519. 520. 521. 522. 523. 524. 525. 526. 527. 528. 529. 530. 531. 532. 533. 534. 535. 536. 537. 538. 539. 540. 541. 542. 543. 544. 545. 546. 547. 548. 549. 550. 551. 552. 553. 554. 555. 556. 557. 558. 559. 560. 561. 562. 563. 564. 565. 566. 567. 568. 569. 570. 571. 572. 573. 574. 575. 576. 577. 578. 579. 580. 581. 582. 583. 584. 585. 586. 587. 588. 589. 590. 591. 592. 593. 594. 595. 596. 597. 598. 599. 600. 601. 602. 603. 604. 605. 606. 607. 608. 609. 610. 611. 612. 613. 614. 615. 616. 617. 618. 619. 620. 621. 622. 623. 624. 625. 626. 627. 628. 629. 630. 631. 632. 633. 634. 635. 636. 637. 638. 639. 640. 641. 642. 643. 644. 645. 646. 647. 648. 649. 650. 651. 652. 653. 654. 655. 656. 657. 658. 659. 660. 661. 662. 663. 664. 665. 666. 667. 668. 669. 670. 671. 672. 673. 674. 675. 676. 677. 678. 679. 680. 681. 682. 683. 684. 685. 686. 687. 688. 689. 690. 691. 692. 693. 694. 695. 696. 697. 698. 699. 700. 701. 702. 703. 704. 705. 706. 707. 708. 709. 710. 711. 712. 713. 714. 715. 716. 717. 718. 719. 720. 721. 722. 723. 724. 725. 726. 727. 728. 729. 730. 731. 732. 733. 734. 735. 736. 737. 738. 739. 740. 741. 742. 743. 744. 745. 746. 747. 748. 749. 750. 751. 752. 753. 754. 755. 756. 757. 758. 759. 760. 761. 762. 763. 764. 765. 766. 767. 768. 769. 770. 771. 772. 773. 774. 775. 776. 777. 778. 779. 780. 781. 782. 783. 784. 785. 786. 787. 788. 789. 790. 791. 792. 793. 794. 795. 796. 797. 798. 799. 800. 801. 802. 803. 804. 805. 806. 807. 808. 809. 810. 811. 812. 813. 814. 815. 816. 817. 818. 819. 820. 821. 822. 823. 824. 825. 826. 827. 828. 829. 830. 831. 832. 833. 834. 835. 836. 837. 838. 839. 840. 84

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* The factor $k_1 = 1000$ when $t \leq 10^{-3}$, and $k_1 = 1$ when $t > 10^{-3}$

Note The variable h , is the magnitude of the sampling interval, is units of seconds.

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TABLE 1

ACCESSIBLE EMISSION LIMITS FOR COLLATERAL
RADIATION FROM LASER PRODUCTS

| |
|--|
| <p>1. <u>Accessible emission limits</u> for collateral radiation having wavelengths greater than 0.6 micrometers but less than or equal to 1.4 micrometers are identical to the accessible emission limits of class I laser radiation as determined from Tables I and IV in this paragraph.</p> <p>2. In the wavelength range of less than or equal to 400 nanometers, for all emission durations.</p> <p>3. In the wavelength range of greater than 400 nanometers, for all emission durations less than or equal to 1×10^{-9} seconds and, when applicable under paragraph 1(c) of this section, for all emission durations.</p> <p><u>Accessible emission limit</u> for collateral radiation within the spectral range of wavelengths as 0.5 millimicrometers or more, exchanged over a rectangular parallelogram in the external surface of the product, having an area of at least centimeters with its dimension greater than 5 centimeters.</p> |
|--|

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- (1) *Beam of a single wavelength.* Laser or collateral radiation of a single wavelength exceeds the accessible emission limits of a class if its accessible emission level is greater than the accessible emission limit of that class within any of the ranges of emission duration specified in tables I, II-A, II, III-A, and III-B of this paragraph.
- (2) *Beam of multiple wavelengths in same range.* Laser or collateral radiation having two or more wavelengths within any one of the wavelength ranges specified in tables I, II-A, II, III-A, and III-B of this paragraph exceeds the accessible emission limits of a class if the sum of the ratios of the accessible emission level to the corresponding accessible emission limit at each such wavelength is greater than unity for that combination of emission duration and wavelength distribution which results in the maximum sum.
- (3) *Beam with multiple wavelengths in different ranges.* Laser or collateral radiation having wavelengths within two or more of the wavelength ranges specified in tables I, II-A, II, III-A, and III-B of this paragraph exceeds the accessible emission limits of a class if it exceeds the applicable limits within any one of those wavelength ranges. This determination is made for each wavelength range in accordance with paragraph (d) (1) or (2) of this section.
- (4) *Class I dual limits.* Laser or collateral radiation in the wavelength range of greater than 400 nm but less than or equal to 1,400 nm exceeds the accessible emission limits of Class I if it exceeds both:
 - (i) The Class I accessible emission limits for radiant energy within any range of emission duration specified in table I of this paragraph, and
 - (ii) The Class I accessible emission limits for integrated radiance within any range of

emission duration specified in table I of this paragraph.

(e) *Tests for determination of compliance*

- (1) *Tests for certification.* Tests on which certification under 1010.2 is based shall account for all errors and statistical uncertainties in the measurement process. Because compliance with the standard is required for the useful life of a product such tests shall also account for increases in emission and degradation in radiation safety with age.
- (2) *Test conditions.* Except as provided in 1010.13, tests for compliance with each of the applicable requirements of this section and 1040.11 shall be made during operation, maintenance, or service as appropriate:
 - (i) Under those conditions and procedures which maximize the accessible emission levels, including start-up, stabilized emission, and shut-down of the laser product; and
 - (ii) With all controls and adjustments listed in the operation, maintenance, and service instructions adjusted in combination to result in the maximum accessible emission level of radiation; and
 - (iii) At points in space to which human access is possible in the product configuration which is necessary to determine compliance with each requirement, e.g., if operation may require removal of portions of the protective housing and defeat of safety interlocks, measurements shall be made at points accessible in that product configuration; and
 - (iv) With the measuring instrument detector so positioned and so oriented with respect to the laser product as to result in the maximum detection of radiation by the instrument; and
 - (v) For a laser product other than a laser system, with the laser coupled to that type of laser energy source which is specified as compatible by the laser product manufacturer and which produces the maximum emission level of accessible radiation from that product.
- (3) *Measurement parameters.* Accessible emission levels of laser and collateral radiation shall be based upon the following measurements as appropriate, or their equivalent:
 - (i) For laser products intended to be used in a locale where the emitted laser radiation is unlikely to be viewed with optical instruments, the radiant power (W) or radiant energy (J) detectable through a circular aperture stop having a diameter of 7 millimeters and within a circular solid angle of acceptance of 1×10^{-3} steradian with collimating optics of 5 diopters or less. For scanned laser radiation, the direction of the solid angle of acceptance shall change as needed to maximize detectable radiation, with an angular speed of up to 5 radians/second. A 50 millimeter diameter aperture stop with the same collimating optics and acceptance angle stated above shall be used for all other laser products (except that a 7 millimeter diameter aperture stop shall be used in the measurement of scanned laser radiation emitted by laser products manufactured on or before August 20, 1986).

- (ii) The irradiance ($\text{W}\cdot\text{cm}^{-2}\cdot\text{sr}^{-1}$) or radiant exposure ($\text{J}\cdot\text{cm}^{-2}$) equivalent to the radiant power (W) or radiant energy (J) detectable through a circular aperture stop having a diameter of 7 millimeters and, for irradiance, within a circular solid angle of acceptance of 1×10^{-3} steradian with collimating optics of 5 diopters or less, divided by the area of the aperture stop (cm^2).
- (iii) The radiance ($\text{W}\cdot\text{cm}^{-2}\cdot\text{sr}^{-1}$) or integrated radiance ($\text{J}\cdot\text{cm}^{-2}\cdot\text{sr}^{-1}$) equivalent to the radiant power (W) or radiant energy (J) detectable through a circular aperture stop having a diameter of 7 millimeters and within a circular solid angle of acceptance of 1×10^{-5} steradian with collimating optics of 5 diopters or less, divided by that solid angle (sr) and by the area of the aperture stop (cm^2).

(f) *Performance requirements*

- (1) *Protective housing.* Each laser product shall have a protective housing that prevents human access during operation to laser and collateral radiation that exceed the limits of Class I and table VI, respectively, wherever and whenever such human access is not necessary for the product to perform its intended function. Wherever and whenever human access to laser radiation levels that exceed the limits of Class I is necessary, these levels shall not exceed the limits of the lowest class necessary to perform the intended function(s) of the product.
- (2) *Safety interlocks.*
 - (i) Each laser product, regardless of its class, shall be provided with at least one safety interlock for each portion of the protective housing which is designed to be removed or displaced during operation or maintenance, if removal or displacement of the protective housing could permit, in the absence of such interlock(s), human access to laser or collateral radiation in excess of the accessible emission limit applicable under paragraph (f)(1) of this section.
 - (ii) Each required safety interlock, unless defeated, shall prevent such human access to laser and collateral radiation upon removal or displacement of such portion of the protective housing
 - (iii) Either multiple safety interlocks or a means to preclude removal or displacement of the interlocked portion of the protective housing shall be provided, if failure of a single interlock would allow;
 - (a) Human access to a level of laser radiation in excess of the accessible emission limits of Class IIIa; or
 - (b) Laser radiation in excess of the accessible emission limits of Class II to be emitted directly through the opening created by removal or displacement of the interlocked portion of the protective housing.
 - (iv) Laser products that incorporate safety interlocks designed to allow safety interlock defeat shall incorporate a means of visual or aural indication of interlock defeat. During interlock defeat, such indication shall be visible or audible whenever the laser product is energized, with and without the associated portion of the protective housing removed or displaced.

- (v) Replacement of a removed or displaced portion of the protective housing shall not be possible while required safety interlocks are defeated.
- (3) *Remote interlock connector.* Each laser system classified as a Class IIIb or IV laser product shall incorporate a readily available remote interlock connector having an electrical potential difference of no greater than 130 root-mean-square volts between terminals. When the terminals of the connector are not electrically joined, human access to all laser and collateral radiation from the laser product in excess of the accessible emission limits of Class I and table VI shall be prevented.
- (4) *Key control.* Each laser system classified as a Class IIIb or IV laser product shall incorporate a key-actuated master control. The key shall be removable and the laser shall not be operable when the key is removed.
- (5) *Laser radiation emission indicator.*
 - (i) Each laser system classified as a Class II or IIIa laser product shall incorporate an emission indicator that provides a visible or audible signal during emission of accessible laser radiation in excess of the accessible emission limits of Class I.
 - (ii) Each laser system classified as a Class IIIb or IV laser product shall incorporate an emission indicator which provides a visible or audible signal during emission of accessible laser radiation in excess of the accessible emission limits of Class I, and sufficiently prior to emission of such radiation to allow appropriate action to avoid exposure to the laser radiation.
 - (iii) For laser systems manufactured on or before August 20, 1986, if the laser and laser energy source are housed separately and can be operated at a separation distance of greater than 2 meters, both laser and laser energy source shall incorporate an emission indicator as required in accordance with paragraph (f)(5) (i) or (ii) of this section. For laser systems manufactured after August 20, 1986, each separately housed laser and operation control of a laser system that regulates the laser or collateral radiation emitted by a product during operation shall incorporate an emission indicator as required in accordance with paragraph (f)(5) (i) or (ii) of this section, if the laser or operation control can be operated at a separation distance greater than 2 meters from any other separately housed portion of the laser product incorporating an emission indicator.
 - (iv) Any visible signal required by paragraph (f)(5) (i) or (ii) of this section shall be clearly visible through protective eyewear designed specifically for the wavelength(s) of the emitted laser radiation.
 - (v) Emission indicators required by paragraph (f)(5) (i) or (ii) of this section shall be located so that viewing does not require human exposure to laser or collateral radiation in excess of the accessible emission limits of Class I and table VI.
- (6) *Beam attenuator.*
 - (i) Each laser system classified as a Class II, III, or IV laser product shall be provided with one or more permanently attached means, other than laser energy source

switch(es), electrical supply main connectors, or the key-actuated master control, capable of preventing access by any part of the human body to all laser and collateral radiation in excess of the accessible emission limits of Class I and table VI.

- (ii) If the configuration, design, or function of the laser product would make unnecessary compliance with the requirement in paragraph (f)(6)(i) of this section, the Director, Office of Compliance (HFZ-300), Center for Devices and Radiological Health, may, upon written application by the manufacturer, approve alternate means to accomplish the radiation protection provided by the beam attenuator.
- (7) *Location of controls.* Each Class IIa, II, III, or IV laser product shall have operational and adjustment controls located so that human exposure to laser or collateral radiation in excess of the accessible emission limits of Class I and table VI is unnecessary for operation or adjustment of such controls.
 - (8) *Viewing optics.* All viewing optics, viewports, and display screens incorporated into a laser product, regardless of its class, shall limit the levels of laser and collateral radiation accessible to the human eye by means of such viewing optics, viewports, or display screens during operation or maintenance to less than the accessible emission limits of Class I and table VI. For any shutter or variable attenuator incorporated into such viewing optics, viewports, or display screens, a means shall be provided:
 - (i) To prevent access by the human eye to laser and collateral radiation in excess of the accessible emission limits of Class I and table VI whenever the shutter is opened or the attenuator varied.
 - (ii) To preclude, upon failure of such means as required in paragraph (f)(8)(i) of this section, opening the shutter or varying the attenuator when access by the human eye is possible to laser or collateral radiation in excess of the accessible emission limits of Class I and table VI.
 - (9) *Scanning safeguard.* Laser products that emit accessible scanned laser radiation shall not, as a result of any failure causing a change in either scan velocity or amplitude, permit human access to laser radiation in excess of:
 - (i) The accessible emission limits of the class of the product, or
 - (ii) The accessible emission limits of the class of the scanned laser radiation if the product is Class IIIb or IV and the accessible emission limits of Class IIIa would be exceeded solely as result of such failure.
 - (10) *Manual reset mechanism.* Each laser system manufactured after August 20, 1986, and classified as a Class IV laser product shall be provided with a manual reset to enable resumption of laser radiation emission after interruption of emission caused by the use of a remote interlock or after an interruption of emission in excess of 5 seconds duration due to the unexpected loss of main electrical power.
- (g) *Labeling requirements.* In addition to the requirements of 1010.2 and 1010.3, each laser

product shall be subject to the applicable labeling requirements of this paragraph.

(1) *Class IIa and II designations and warnings.*

(i) Each Class IIa laser product shall have affixed a label bearing the following wording: "Class IIa Laser Product--Avoid Long-Term Viewing of Direct Laser Radiation."

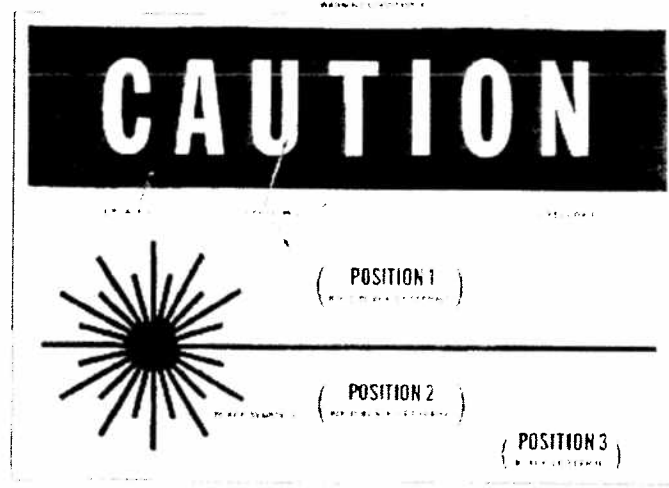
(ii) Each Class II laser product shall have affixed a label bearing the warning logotype A (figure 1 in this paragraph) and including the following wording:

[Position 1 on the logotype]

"LASER RADIATION--DO NOT STARE INTO BEAM"; and

[Position 3 on the logotype]

"CLASS II LASER PRODUCT".



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(2) *Class IIIa and IIIb designations and warnings.*

(i) Each Class IIIa laser product with an irradiance less than or equal to $2.5 \times 10^{-3} \text{ W} \cdot \text{cm}^{-2}$ shall have affixed a label bearing the warning logotype A (figure 1 of paragraph (g)(1)(ii) of this section) and including the following wording:

[Position 1 on the logotype]

"LASER RADIATION--DO NOT STARE INTO BEAM OR VIEW
DIRECTLY WITH OPTICAL INSTRUMENTS"; and,

[Position 3 on the logotype]

"CLASS IIIa LASER PRODUCT".

(ii) Each Class IIIa laser product with an irradiance greater than $2.5 \times 10^{-3} \text{ W} \cdot \text{cm}^{-2}$ shall have affixed a label bearing the warning logotype B (figure 2 in this paragraph) and

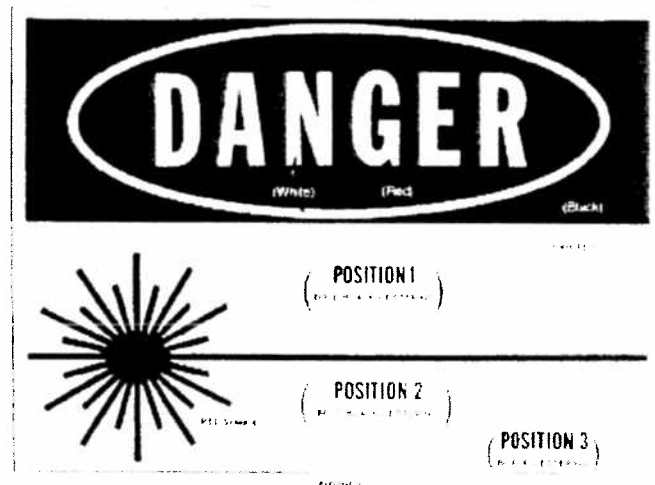
including the following wording:

[Position 1 on the logotype]

"LASER RADIATION--AVOID DIRECT EYE EXPOSURE"; and,

[Position 3 on the logotype]

"CLASS IIIa LASER PRODUCT".



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- (iii) Each Class IIIb laser product shall have affixed a label bearing the warning logotype B (figure 2 of paragraph (g)(2)(ii) of this section) and including the following wording:

[Position 1 on the logotype]

"LASER RADIATION--AVOID DIRECT EXPOSURE TO BEAM"; and,

[Position 3 on the logotype]

"CLASS IIIb LASER PRODUCT".

- (3) *Class IV designation and warning.* Each Class IV laser product shall have affixed a label bearing the warning logotype B (figure 2 of paragraph (g)(2)(ii) of this section), and including the following wording:

[Position 1 on the logotype]

"LASER RADIATION--AVOID EYE OR SKIN EXPOSURE TO DIRECT OR SCATTERED RADIATION"; and,

[Position 3 on the logotype]

"CLASS IV LASER PRODUCT".

- (4) *Radiation output information on warning logotype.* Each Class II, III, and IV laser product shall state in appropriate units, at position 2 on the required warning logotype,

the maximum output of laser radiation, the pulse duration when appropriate, and the laser medium or emitted wavelength(s).

- (5) *Aperture label* Each laser product, except medical laser products and Class IIa laser products, shall have affixed, in close proximity to each aperture through which is emitted accessible laser or collateral radiation in excess of the accessible emission limits of Class I and table VI of paragraph (d) of this section, a label(s) bearing the following wording as applicable.
- (i) "AVOID EXPOSURE--Laser radiation is emitted from this aperture," if the radiation emitted through such aperture is laser radiation.
 - (ii) "AVOID EXPOSURE--Hazardous electromagnetic radiation is emitted from this aperture," if the radiation emitted through such aperture is collateral radiation described in table VI, item 1.
 - (iii) "AVOID EXPOSURE--Hazardous x-rays are emitted from this aperture," if the radiation emitted through such aperture is collateral radiation described in table VI, item 2.
- (6) *Labels for noninterlocked protective housings* For each laser product, labels shall be provided for each portion of the protective housing which has no safety interlock and which is designed to be displaced or removed during operation, maintenance, or service, and thereby could permit human access to laser or collateral radiation in excess of the limits of Class I and table VI. Such labels shall be visible on the protective housing prior to displacement or removal of such portion of the protective housing and visible on the product in close proximity to the opening created by removal or displacement of such portion of the protective housing, and shall include the wording:
- (i) "CAUTION--Laser radiation when open. DO NOT STARE INTO BEAM," for Class II accessible laser radiation.
 - (ii) "CAUTION--Laser radiation when open. DO NOT STARE INTO BEAM OR VIEW DIRECTLY WITH OPTICAL INSTRUMENTS," for Class IIIa accessible laser radiation with an irradiance less than or equal to $2.5 \times 10^{-3} \text{ W} \cdot \text{cm}^{-2}$.
 - (iii) "DANGER--Laser radiation when open. AVOID DIRECT EYE EXPOSURE," for Class IIIa accessible laser radiation with an irradiance greater than $2.5 \times 10^{-3} \text{ W} \cdot \text{cm}^{-2}$.
 - (iv) "DANGER--Laser radiation when open. AVOID DIRECT EXPOSURE TO BEAM," for Class IIb accessible laser radiation.
 - (v) "DANGER--Laser radiation when open. AVOID EYE OR SKIN EXPOSURE TO DIRECT OR SCATTERED RADIATION," for Class IV accessible laser radiation.
 - (vi) "CAUTION--Hazardous electromagnetic radiation when open," for collateral radiation in excess of the accessible emission limits in table VI, item 1 of paragraph (d) of this section.
 - (vii) "CAUTION--Hazardous x-rays when open," for collateral radiation in excess of the

accessible emission limits in table VI, item 2 of paragraph (d) of this section.

- (7) *Labels for defeatably interlocked protective housings.* For each laser product, labels shall be provided for each defeatably interlocked (as described in paragraph (f)(2)(iv) of this section) portion of the protective housing which is designed to be displaced or removed during operation, maintenance, or service, and which upon interlock defeat could permit human access to laser or collateral radiation in excess of the limits of Class I or table VI. Such labels shall be visible on the product prior to and during interlock defeat and in close proximity to the opening created by the removal or displacement of such portion of the protective housing, and shall include the wording:
- (i) "CAUTION--Laser radiation when open and interlock defeated. DO NOT STARE INTO BEAM." for Class II accessible laser radiation.
 - (ii) "CAUTION--Laser radiation when open and interlock defeated. DO NOT STARE INTO BEAM OR VIEW DIRECTLY WITH OPTICAL INSTRUMENTS." for Class IIIa accessible laser radiation with an irradiance less than or equal to $2.5 \times 10^{-3} \text{ W} \cdot \text{cm}^{-2}$.
 - (iii) "DANGER--Laser radiation when open and interlock defeated. AVOID DIRECT EYE EXPOSURE." for Class IIIa accessible laser radiation when an irradiance greater than $2.5 \times 10^{-3} \text{ W} \cdot \text{cm}^{-2}$.
 - (iv) "DANGER--Laser radiation when open and interlock defeated. AVOID DIRECT EXPOSURE TO BEAM." for Class IIIb accessible laser radiation.
 - (v) "DANGER--Laser radiation when open and interlock defeated. AVOID EYE OR SKIN EXPOSURE TO DIRECT OR SCATTERED RADIATION." for Class IV accessible laser radiation.
 - (vi) "CAUTION--Hazardous electromagnetic radiation when open and interlock defeated." for collateral radiation in excess of the accessible emission limits in table VI, item 1 of paragraph (d) of this section.
 - (vii) "CAUTION--Hazardous x-rays when open and interlock defeated." for collateral radiation in excess of the accessible emission limits in table VI, item 2 of paragraph (d) of this section.
- (8) *Warning for visible and/or invisible radiation.* On the labels specified in this paragraph, if the laser or collateral radiation referred to is:
- (i) Invisible radiation, the word "invisible" shall appropriately precede the word "radiation"; or
 - (ii) Visible and invisible radiation, the words "visible and invisible" or "visible and/or invisible" shall appropriately precede the word "radiation."
 - (iii) Visible laser radiation only, the phrase "laser light" may replace the phrase "laser radiation."
- (9) *Positioning of labels.* All labels affixed to a laser product shall be positioned so as

to make unnecessary, during reading, human exposure to laser radiation in excess of the accessible emission limits of Class I radiation or the limits of collateral radiation established to table VI of paragraph (d) of this section.

- (10) *Label specifications.* Labels required by this section and 1040.11 shall be permanently affixed to, or inscribed on, the laser product, legible, and clearly visible during operation, maintenance, or service, as appropriate. If the size, configuration, design, or function of the laser product would preclude compliance with the requirements for any required label or would render the required wording of such label inappropriate or ineffective, the Director, Office of Compliance (HFZ-300), Center for Devices and Radiological Health, on the Director's own initiative or upon written application by the manufacturer, may approve alternate means of providing such label(s) or alternate wording for such label(s) as applicable.

(h) *Informational requirements*

- (1) *User information.* Manufacturers of laser products shall provide as an integral part of any user instruction or operation manual which is regularly supplied with the product, or, if not so supplied, shall cause to be provided with each laser product:
- (i) Adequate instructions for assembly, operation, and maintenance, including clear warnings concerning precautions to avoid possible exposure to laser and collateral radiation in excess of the accessible emission limits in tables I, II-A, II, III-A, III-B, and VI of paragraph (d) of this section, and a schedule of maintenance necessary to keep the product in compliance with this section and 1040.11.
 - (ii) A statement of the magnitude, in appropriate units, of the pulse durations(s), maximum radiant power and, where applicable, the maximum radiant energy per pulse of the accessible laser radiation detectable in each direction in excess of the accessible emission limits in table I of paragraph (d) of this section determined under paragraph (e) of this section.
 - (iii) Legible reproductions (color optional) of all labels and hazard warnings required by paragraph (g) of this section and 1040.11 to be affixed to the laser product or provided with the laser product, including the information required for positions 1, 2, and 3 of the applicable logotype (figure 1 of paragraph (g)(1)(ii) or figure 2 or paragraph (g)(2)(ii) of this section). The corresponding position of each label affixed to the product shall be indicated or, if provided with the product, a statement that such labels could not be affixed to the product but were supplied with the product and a statement of the form and manner in which they were supplied shall be provided.
 - (iv) A listing of all controls, adjustments, and procedures for operation and maintenance, including the warning "Caution--use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous radiation exposure."
 - (v) In the case of laser products other than laser systems, a statement of the compatibility requirements for a laser energy source that will assure compliance of

the laser product with this section and 1040.11.

- (vi) In the case of laser products classified with a 7 millimeter diameter aperture stop as provided in paragraph (e)(3)(i) of this section, if the use of a 50 millimeter diameter aperture stop would result in a higher classification of the product, the following warning shall be included in the user information: "CAUTION--The use of optical instruments with this product will increase eye hazard."
- (2) *Purchasing and servicing information.* Manufacturers of laser products shall provide or cause to be provided:
- (i) In all catalogs, specification sheets, and descriptive brochures pertaining to each laser product, a legible reproduction (color optional) of the class designation and warning required by paragraph (g) of this section to be affixed to that product, including the information required for positions 1, 2, and 3 of the applicable logotype (figure 1 of paragraph (g)(1)(ii) or figure 2 of paragraph (g)(2)(ii) of this section).
 - (ii) To servicing dealers and distributors and to others upon request at a cost not to exceed the cost of preparation and distribution, adequate instructions for service adjustments and service procedures for each laser product model, including clear warnings and precautions to be taken to avoid possible exposure to laser and collateral radiation in excess of the accessible emission limits in tables I, II-A, II, III-A, III-B, and VI of paragraph (d) of this section, and a schedule of maintenance necessary to keep the product in compliance with this section and 1040.11; and in all such service instructions, a listing of those controls and procedures that could be utilized by persons other than the manufacturers or the manufacturer's agents to increase accessible emission levels of radiation and a clear description of the location of displaceable portions of the protective housing that could allow human access to laser or collateral radiation in excess of the accessible emission limits in tables I, II-A, II, III-A, III-B, and VI of paragraph (d) of this section. The instructions shall include protective procedures for service personnel to avoid exposure to levels of laser and collateral radiation known to be hazardous for each procedure or sequence of procedures to be accomplished, and legible reproductions (color optional) of required labels and hazard warnings.
 - (i) *Modification of a certified product.* The modification of a laser product, previously certified under 1010.2, by any person engaged in the business of manufacturing, assembling, or modifying laser products shall be construed as manufacturing under the act if the modification affects any aspect of the product's performance or intended function(s) for which this section and 1040.11 have an applicable requirement. The manufacturer who performs such modification shall recertify and re-identify the product in accordance with the provisions of 1010.2. and 1010.3.

¹ Class I levels of laser radiation are not considered to be hazardous.

² Class IIa levels of laser radiation are not considered to be hazardous if viewed for any period of time less than or equal to 1×10^3 seconds but are considered to be a chronic

viewing hazard for any period of time greater than 1×10^3 seconds.

- ³ Class II levels of laser radiation are considered to be a chronic viewing hazard.
 - ⁴ Class IIIa levels of laser radiation are considered to be, depending upon the irradiance, either an acute intrabeam viewing hazard or chronic viewing hazard, and an acute viewing hazard if viewed directly with optical instruments.
 - ⁵ Class IIIb levels of laser radiation are considered to be an acute hazard to the skin and eyes from direct radiation.
 - ⁶ Class IV levels of laser radiation are considered to be an acute hazard to the skin and eyes from direct and scattered radiation.
- (1) The factors k_1 and k_2 are wavelength-dependent correction factors determined from table IV.
 - (2) The variable t in the expressions of emission limits is the magnitude of the sampling interval in units of seconds.

Notes applicable to tables I, II-A, II, III-A and III-B:

[50 FR 33688, Aug. 20, 1985; 50 FR 42156, Oct. 18, 1985; 65 FR 17138, Mar. 31, 2000]

**Table H1. Comparison of National and
International Standards for Classification**

| Class | IEC 60825-1 | US: FDA/CDRH | ANSI-Z136.1 |
|-----------------|---|---|--|
| Class 1 | Any laser or laser system containing a laser that cannot emit laser radiation at levels that are known to cause eye or skin injury during normal operation. This does not apply to service periods requiring access to Class 1 enclosures containing higher-class lasers. | | |
| Class 1M | Not known to cause eye or skin damage unless collecting optics are used. | N/A | Considered incapable of producing hazardous exposure unless viewed with collecting optics. |
| Class 2a | N/A | Visible lasers that are not intended for viewing and cannot produce any known eye or skin injury during operation based on a maximum exposure time of 1000 s. | N/A |
| Class 2 | Visible lasers considered incapable of emitting laser radiation at levels that are known to cause skin or eye injury within the time period of the human eye aversion response (0.25 s). | | |
| Class 2M | Not known to cause eye or skin damage within the aversion response time unless collecting optics are used. | N/A | Emits in the visible portion of the spectrum, and is potentially hazardous if viewed with collecting optics. |

**Table H1. Comparison of National and
International Standards for Classification (cont.)**

| Class | IEC 60825-1 | US: FDA/CDRH | ANSI-Z136.1 |
|-----------------|---|---|--|
| Class 3a | N/A | Lasers similar to Class 2 with the exception that collecting optics cannot be used to directly view the beam.

Visible Only | N/A |
| Class 3R | Replaces Class 3a and has different limits. Up to 5 times the Class 2 limit for visible and 5 times the Class 1 limits for some invisible. | N/A | A laser system that is potentially hazardous under some direct and specular reflection viewing condition if the eye is appropriately focused and stable. |
| Class 3B | Medium-powered lasers (visible or invisible regions) that present a potential eye hazard for intrabeam (direct) or specular (mirror-like) conditions. Class 3B lasers do not present a diffuse (scatter) hazard or significant skin hazard except for higher powered 3B lasers operating at certain wavelength regions. | | |
| Class 4 | High-powered lasers (visible or invisible) are considered to present potential acute hazard to the eye and skin for both direct (intrabeam) and scatter (diffused) conditions. Also have potential hazard considerations for fire (ignition) and byproduct emissions from target or process materials. | | |

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