

AUBURN UNIVERSITY LASER SAFETY MANUAL

**RADIATION SAFETY OFFICE
RISK MANAGEMENT and SAFETY**

June 2007

CONTENTS

<u>SECTION</u>	<u>PAGE</u>
1. General.....	1
1.1 Scope.....	1
1.2 Application	1
1.3 Laser Safety Programs	2
2. Definitions	4
3. Hazard Evaluation and Classification.....	10
3.1 General.....	10
3.2 Laser Considerations	10
3.3 Environment in Which the Laser is Used	10
3.4 Personnel.....	11
4. Control Measures.....	11
4.1 General Considerations.....	11
4.2 Substitution of Alternate Control Measures (Class 3B or Class 4)	14
4.3 Engineering Controls	14
4.4 Administrative and Procedural Controls (Class 3B and Class 4)	19
4.5 Special Considerations.....	20
4.6 Protective Equipment.....	20
4.7 Area Warning Signs and Labels	23
5. Education and Training	25
5.1 General.....	25
5.2 User Training	25
6. Medical Examinations	25
6.1 Examinations Following a Suspected or Actual Laser-Induced Injury	25
6.2 Medical Surveillance	25
6.3 General Procedures.....	26
6.4 Frequency of Medical Examinations	26
7. Non-Beam Hazards.....	26
7.1 General.....	26
7.2 Physical Agents	26
7.3 Chemical Agents.....	28
7.4 Biological Agents	30
7.5 Human Factors.....	30
8. Criteria for Exposures of Eye and Skin.....	30
8.1 Ocular Exposures From Point Sources and Extended Sources.....	31
8.2 MPE for Ocular Exposures	31
8.3 Special Qualifications for Ocular Exposures	32

Appendix A Tables

Table 2. Recommended Limiting Exposure Durations for CW and Repetitive-Pulse MPE Calculations..... 33

Table 3. Diffusely Reflected Beam Energy in Joules that does not Exceed the MPE 34

Table 4. Simplified Method for Selecting Laser Eye Protection for Point Source Viewing (Wavelengths Between 0.400 and 1.400 m..... 35

Table 5a. Maximum Permissible Exposure (MPE) for Point Source Ocular Exposure to a Laser Beam..... 36

Table 5b. Maximum Permissible Exposure (MPE) for Extended Source Ocular Exposure..... 37

Table 6. Parameters and Correction Factors 38

Table 7. Maximum Permissible Exposure (MPE) Skin Exposure to a Laser Beam 39

Table 10. Control Measures for the Seven Laser Classes 40

Appendix B Figures

Figure 1 a. Sample Warning Sign for Class 2 and Class 2M Lasers..... 43

Figure 1b. Sample Warning Sign for Class 3R, Class 3B, and Class 4 Lasers 44

Figure 1c. IEC Warning Logo and Information Label..... 45

Figure 1d. Sample Warning Sign for Facility Policy, for example, Outside a Temporary Laser Controlled Area During Periods of Service..... 46

Figure 2a. Area/Entryway Safety Controls for Class 4 Lasers Utilizing Entryway Interlocks..... 47

Figure 2b. Entryway Safety Controls for Class 4 Lasers without Entryway Interlocks..... 48

Figure 4. Point Source MPEs for Visible and Near Infrared Pulsed Sources (Wavelengths from 0.400 to 1.400 m)..... 49

Figure 5. MPE for Ultraviolet Radiation (Small and Extended Sources) for Exposure Duration from 10⁻⁹ to 3 10⁴ s for Ocular Exposure and 10⁻⁹ to 103 s for Skin Exposure..... 50

Figure 6. MPE for UV and IR Radiation for Single Pulse/Continuous Exposure..... 51

Figure 7. MPE Ocular Exp to Visible Laser Rad. for Single Pulse/Continuous Exp.....52

Appendix C Hazard Evaluation, Classification and Control Measures

C.1 Alternate Labeling.....53

C.2 Laser Protection Damage Threshold Evaluation.....53

C.3 Examples of Typical Laser System Classification and MPE's for Select Lasers.....54

Table C1. Typical Laser Classification – Continuous Wave (CW) Point Source Lasers..... 55

Table C2. Typical Laser Classification – Single-Pulse Point Source Lasers 56

Table C3a. Point Source MPE for the Eye for Selected CW Lasers..... 57

Table C3b. Point Source MPE for the Skin for Selected CW Lasers..... 57

Table C4. Point Source MPE for Eye and for Skin for Selected Single-Pulse Lasers..... 58

Appendix D Guide for Employee Laser Safety Training Programs

D.1 Employee Training..... 59

SECTION

PAGE

Appendix E Medical Examinations

E1. Medical Referral Following Suspected or Known Laser Injury..... 60
E2. Medical Surveillance Examinations 60
E3. Medical Examinations 60
E4. Records and Record Retention 61
E5. Access to Records..... 61

Appendix F Non-Beam Hazards

F1. Physical Agents 62
F2. Chemical Agents..... 63
F3. Biological Agents 64
Table F1a. Laser Generated Air Contaminant (LGAC) Thresholds..... 65
Table F1b. Laser Generated Airborne Contaminants 65
Table F1 c. Control Measures for Laser Generated Air Contaminants (LGAC)..... 69

Appendix G. Sample SOP 70

Appendix H. Primary Investigator User Application..... 74

Auburn University Laser Safety Manual

1. General

1.1 Scope.

This manual provides recommendations for the safe use of laser systems that operate at wavelengths between 0.18 m and 1 mm, being used in Auburn University research and/or teaching facilities. To achieve this, the university has adopted the American National Standard for the Safe Use of Lasers, ANSI Z136.1-2007, which is recognized as a minimum standard for laser safety. This manual follows the general outline of the standard, and chapters and paragraphs are directly correlatable. A copy of ANSI Z136.1-2007 is available at the radiation Safety Office located in room 201 of Leach Science Center.

1.2 Application.

The objective of this manual is to provide reasonable and adequate guidance for the safe use of lasers and laser systems at Auburn University. The basis of a lasers hazard is the ability of the laser beam to cause biological damage to the eye or skin during use. For example:

A Class 1 laser system is: Considered to be incapable of producing damaging radiation levels during operation, and is exempt from control measures or other surveillance forms.

A Class 1M laser system is: Considered incapable of producing hazardous exposures during normal operations unless directly viewed with optical instruments (eye-loupe / telescope); Exempt from control measures other than to prevent potentially hazardous optically aided viewing; and exempt from other surveillance forms

A Class 2 laser system: Emits in the visible spectrum (0.4 to 0.7 μm), and eye protection is normally afforded by the eyes aversion response.

A Class 2M laser system: Eye protection normally afforded by the aversion response; however, Class 2M is potentially hazardous if viewed with certain optical aids.

A Class 3 laser system (medium-power): May be hazardous for direct/specular reflection viewing conditions, but normally not a diffuse reflection/fire hazard. Has two subclasses:

A Class 3R laser system is potentially hazardous under some direct/specular reflection viewing conditions if eye is appropriately focused/stable. Not a fire hazard or diffuse-reflection hazard.

A Class 3B laser system may be hazardous under direct and specular reflection viewing conditions, but is normally not a diffuse reflection or fire hazard.

A Class 4 laser system (high-power):

Is a hazard to the eye or skin from the direct beam, and

May pose a diffuse reflection or fire hazard, and may also produce laser generated air contaminants (LGAC) and hazardous plasma radiation (Section 7).

Table 1. Requirements by Laser Classification

Note: During maintenance and service the classification associated with the maximum level of accessible laser radiation shall be used to determine the applicable control measures.

- 1) *Not required except for conditions of intentional intrabeam exposure applications.*
- 2) *Certain uses of Class 1M or 2M laser systems that exceed Class 1 or 2 because they do not satisfy Measurement Condition 1 may require hazard evaluation / manufacturer's information.*

The laser hazard classification system is based entirely on the laser radiation emission. Non-beam hazards must be dealt with separately and are addressed in Section 7.

Class	Procedural & Administrative Controls	Training	Medical Surveillance	LSO
1	Not Required	Not Required	Not Required	Not Required
1M	Required	Application Dependent (2)	Application Dependent (2)	Application Dependent (2)
2	Not Required (1)	Not Required (1)	Not Required	Not Required
2M	Required	Application Dependent (2)	Application Dependent (2)	Application Dependent (2)
3R	Not Required (1)	Not Required (1)	Not Required	Not Required (1)
3B	Required	Required	Required	Required
4	Required	Required	Required	Required

1.3 Laser Safety Program.

1.3.1 General.

Auburn University (employer) has the fundamental responsibility for the assurance of the safe use of lasers owned and/or operated in facilities under its control. Auburn University shall establish and maintain an adequate program for the control of laser hazards. Auburn University safety programs and employee training programs shall be provided for users of Class 3B or Class 4 lasers and laser systems, embedded or not embedded.

1.3.2 Program Provisions.

The laser safety program established by Auburn University shall include provisions for the following:

- 1) Designation of an individual as the Laser Safety Officer (LSO).
- 2) Education of authorized personnel in the safe use of lasers and laser systems.
- 3) Application of adequate protective measures for the control of laser hazards as required in Section 4.
- 4) Incident investigation, including reporting of alleged accidents to the LSO, and preparation of action plans for the prevention of future accidents following a known or suspected incident.
- 5) Appropriate medical examination /surveillance program in accordance with Section 6.

1.3.3 Personnel Responsibilities.

1.3.3.1 Laser Safety Officer (LSO)

1.3.3.1.1 General. The LSO is an individual designated by Auburn University 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 to accompany the responsibility.

1.3.3.1.2 LSO Specific Duties and Responsibilities.

- (1) **Safety Program.** Shall establish and maintain adequate policies and procedures for the control of laser hazards that shall comply with applicable requirements, including federal, state and local regulations.
- (2) **Classification.** Shall classify/verify classifications of laser systems used at AU.
- (3) **Hazard Evaluation.** Shall be responsible for hazard evaluation of work areas.
- (4) **Control Measures.** Shall be responsible for assuring that control measures are implemented and maintained in effect.
- (5) **Procedure Approvals.** Shall approve laser standing operating procedures (SOPs), and procedures that are part of requirements for administrative/procedural controls.
- (6) **Protective Equipment.** Shall recommend / approve protective equipment (eyewear, clothing, barriers, screens, etc) as required to assure safety. Shall assure that equipment is audited periodically to assure proper working order.
- (7) **Signs and Labels.** Shall review the wording on area signs / equipment labels.
- (8) **Facility and Equipment.** Shall review Class 3B and 4 laser installations, facilities and equipment prior to use. Also applies to modification of existing facilities or equipment.
- (9) **Training.** Shall assure that adequate training is provided to laser personnel.
- (10) **Medical Surveillance.** Shall determine personnel categories for surveillance.
- (11) **Records.** Shall assure required records are maintained.
- (12) **Audits and Inspections.** Shall periodically audit for presence / functionality of safety features /control measures required. Shall accompany regulatory inspectors reviewing the program/investigating an incident, and document any discrepancies/issues noted. Shall assure corrective action is taken, where required.
- (13) **Accidents.** Shall develop a plan to respond to notifications of incidents of actual or suspected exposure to potentially harmful laser radiation. Plan should include the provision of medical assistance for potentially exposed individual, investigation of the incident and documentation and reporting of the results.
- (14) **Approval of Laser Systems Operations.** Approval of Class 3B or 4 laser system for operation shall be given only if LSO is satisfied laser hazard control measures are adequate. These include SOP's for operation /maintenance / service within enclosed and unenclosed systems. Procedures should include consideration of non-beam hazards.

1.3.3.2 Laser Safety Committee

The Laser safety program will be the responsibility of the Radiation Safety Committee. The Radiation Safety Committee will review and approve all Primary Investigators, laser registry forms, laser acquisition forms, and a comprehensive laser safety program, and make policy recommendations, to the University administration.

1.3.3.3 Primary Investigator (PI) and Supervisor for laser system responsibilities

- (1) Immediate supervision of all laser systems in their labs or that they are operating.
- (2) Providing/implementing/ enforcing the safety requirements prescribed in the program.
- (3) Providing operators and others in their labs, with training in the administrative, alignment, and SOPs (Appendix G) for the lasers in question.
- (4) Classifying and labeling of all their lasers.
- (5) Completing an Application for Use of Laser form, (Appendix H) and sending it to the Radiation Safety Office in Risk Management and Safety for approval.
- (6) Train employees who work with Class 1M, 2, 2M, 3R, and 3M lasers, in safe use. Training shall be documented. (See the RMS website for documentation forms.)
- (7) Ensuring operators / employees who work with or around Class 3B and 4 lasers receive AU Laser Safety Training. Training shall be documented. (See the RMS website for documentation forms.)
- (8) Register all users of Class 3B or 4 lasers with the AU Medical Surveillance Program.
- (9) Notify LSO immediately in event of exposure/suspected exposure to Class 3 / 4 lasers.

1.3.3.4 Responsibility of Employees Operating/Working with Lasers. Employees shall:

- (1) Not energize/work with/near a laser unless authorized by the PI/supervisor of laser.
- (2) Comply with safety rules / procedures prescribed by supervisor and LSO. Be familiar with all applicable administrative / alignment / operating procedures, per the SOP.
- (3) When employee knows or suspects an accident has occurred involving any laser or employee, and that such accident has caused, or could potentially have caused, an injury, they shall immediately inform the PI/supervisor or the LSO.
- (4) Completing the AU Laser Safety Training program for Class 3B and 4 lasers.
- (5) Registering with the AU Medical Surveillance Program for Class 3B and 4 users.

1.3.3.5 Other Personnel. Anyone involved in purchasing a Class 3B or 4 laser system shall contact the LSO. This may include purchasing, accounting, building management, etc.

2. Definitions

The definitions listed below are based on a pragmatic rather than a basic approach. Therefore, the definitions are limited to those actually used in this manual 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.

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

attenuation. The decrease in the radiant flux as it passes through an absorbing 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 manual, the aversion response is assumed to limit the exposure of a specific retinal area to 0.25 s. See blink reflex.

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

beam diameter. Distance between diametrically opposed points in 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.

blink reflex. The blink reflex is the involuntary closure of the eyes as a result of stimulation by an external event such as an irritation of the cornea or conjunctiva, a bright flash, the rapid approach of an object, an auditory stimulus or with facial movements. In this manual the ocular aversion response for a bright flash of light is assumed to limit the exposure of a specific retinal area to 0.25 s. See aversion response.

carcinogen. An agent potentially capable of causing cancer.

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 which 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.

collimated beam. A “parallel” beam of light with low divergence or convergence.

continuous wave (CW). In this standard, a laser operating with a continuous output for a period > 0.25 s 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.

cornea. The transparent outer layer of the human eye which 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 0.40 and 1.05 μm , and 20 kHz for wavelengths between 1.05 and 1.40 μm .

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. Increase in diameter of laser beam with distance from the exit aperture.

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

effective power. Power, in watts, through the applicable measurement aperture.

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.

energy. The capacity for doing work. Energy content is commonly used to characterize the output from pulsed lasers, and is generally expressed in joules (J).

epithelium (of the cornea). Layer of cells forming the outer surface of the cornea.

erythema. Redness of the skin due to exposure from laser radiation.

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

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

field of view. The full solid angle from which a detector 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.

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

infrared. In this manual, region of the electromagnetic spectrum between the long-wavelength extreme of visible spectrum ($\sim 0.7\mu\text{m}$) and the shortest microwaves ($\sim 1\text{mm}$).

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

intrabeam viewing. Viewing condition where eye is exposed to all/part of laser beam.

iris. The circular pigmented structure which lies behind the cornea of the human eye. The iris is perforated by the pupil.

irradiance. Radiant power incident per unit area upon a surface, expressed in watts-percentimeter-squared (W cm^{-2}).

joule. A unit of energy. $1 \text{ joule} = 1 \text{ Nm}$; $1 \text{ joule} = 1 \text{ watt} \cdot \text{second}$.

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 temporally, or spatially, or both. An acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation.

laser barrier. A device used to block or attenuate 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 or the determination thereof. 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. Laser employing a forwardbiased semiconductor junction as the medium.

laser personnel. Persons who routinely work around hazardous laser beams.

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 1, 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 which includes a laser.

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

macula. The small uniquely pigmented specialized area of the retina of the eye, which 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. Makes a diverging laser beam more hazardous (e.g., using a magnifying optic to view an optical fiber with a laser beam emitted).

maintenance. Performance of those adjustments / procedures (specified in the user information provided by the manufacturer and considered preventive, to maintain optimal laser performance), which 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. 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 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 (μm) = 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.

ocular fundus. The interior posterior surface of the eye (the retina), as seen upon ophthalmoscopic examination.

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*.

ophthalmoscope. 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 *telescopic viewing* or *magnified viewing*).

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

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 which increase the sensitivity of a material to exposure by optical radiation.

pigment epithelium (of the retina). The layer of cells which 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 is equal to or less than the limiting angular subtense.

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

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

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

pulsed laser. A laser which 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. Variable aperture in the iris through which light travels to interior of the eye.

Q-switch. Device for producing very short, intense laser pulses by enhancing the storage and dumping of electronic 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 a circle by an arc whose length is equal to the radius of the circle. 1 radian ~ 57.3 degrees; 2 radians = 360 degrees.

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

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

radiant exposure. Surface density of the radiant energy received, expressed in units ofjoulesper-centimeter squared ($J\text{ cm}^{-2}$).

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

radiant power. Power emitted, transferred, or received in the form of radiation, expressed in watts (W). See *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.

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). Denoted by n , the ratio of the velocity of light in a vacuum to the phase velocity in the medium.

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

retina. Sensory tissue that receives the incident image formed by cornea & lens of eye.

retinal hazard region. Optical radiation with wavelengths between 0.4 and 1.4 μm , where the principal hazard is usually to the retina.

safety latch. A mechanical device designed to require a conscious decision to override the latch 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. 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. Solid angle is expressed in steradians (sr).

SOP. A Standing Operating Procedure (SOP) is a document produced by the PI that describes, in detail, the particulars of the laser lab in question. (Appendix G)

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 4 steradians about any point in space.

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

T1. The exposure duration (time) at which MPEs based upon thermal injury are replaced by MPEs based upon photochemical injury to the retina.

T2. The exposure duration (time) beyond which extended source MPEs based upon thermal injury are expressed as a constant irradiance.

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 generally collects light through a large aperture thus magnifying hazards from large-beam, collimated lasers.

thermal effect. Caused by temperature elevation of target due to laser exposure.

threshold limit (TL). Term is applied to laser protective eyewear filters, protective windows, and barriers. Expression of the “resistance factor” for beam penetration of a laser protective device. Generally related by the TL of the protective device, expressed in $W\text{ cm}^{-2}$ or $J\text{ cm}^{-2}$. Maximum average irradiance or radiant exposure at given beam diameter for which a protective device provides adequate resistance. So, exposures delivered on the device at or below the TL will limit beam penetration to levels at or below the applicable MPE.

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 0.18 and 0.40 μm (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.

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 windows.

visible radiation (light). The term is used to describe electromagnetic radiation which can be detected by the human eye. In this manual, this term is used to describe wavelengths which lie in the range 0.4 to 0.7 μm .

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 one peak to the next).

work practices. Procedures used to accomplish a task.

3. Hazard Evaluation and Classification

3.1 General.

Several aspects of the application of a laser or laser system influence the total laser hazard evaluation and, thereby, influence the application of control measures:

- (1) Laser system's capability of injuring personnel or interfering with task performance.
- (2) Environment in which the laser is used, including possible access to beam path.
- (3) The personnel who may use or be exposed to laser radiation

Note: See also Section 7 Non-Beam Hazards such as those resulting from interactions with the beam during its intended operation.

The laser hazard class is based on the laser's capability of injuring personnel (first half of aspect (1) above). Any laser or laser system shall be classified according to its accessible radiation during operation. Classification labeling used in conformance with the Federal Laser Product Performance Standard may be used to satisfy this labeling requirement. However, if the laser has been modified subsequent to classification by the manufacturer, the laser may have to be re-classified (see Section 4.1.2).

Aspects (2) and (3) vary with each laser application and cannot be readily standardized. The total hazard evaluation procedure shall consider all aspects, although in most cases only aspect (1) influences the control measures which are applicable.

3.2 Laser Considerations.

The LSO shall ensure that laser output data are valid. Classification shall be based on the maximum output power or radiant energy available for the intended use.

3.2.1 Multiwavelength Lasers. Classification of laser systems capable of emitting many wavelengths shall be based on the most hazardous possible operation (Section 8.2.1).

3.2.2 Repetitive-Pulse Lasers. Evaluation of repetitive-pulse lasers/exposures requires use of correction factors (ANSI Z136.1-2007).

3.2.3 Radiometric Parameters of Laser Required for Laser Hazard Classification.

3.2.3.1 Classification of essentially all lasers requires the following parameters:

- (1) Wavelength(s) or wavelength range
- (2) For CW or repetitive-pulse lasers: average power output within specified limiting apertures (effective power) and limiting exposure duration inherent in the design or intended use of the laser or laser system
- (3) For pulsed lasers: total energy per pulse (or peak power) within specified limiting apertures (effective energy), pulse duration, pulse repetition frequency, and emergent beam radiant exposure

3.3 Environment in Which the Laser is Used.

Following laser system classification, environmental factors require consideration. Their importance in the total hazard evaluation depends on the laser classification. The decision by the LSO to employ additional control measures is influenced by environmental considerations principally for Class 3B and 4 laser systems. The probability of personnel exposure to hazardous laser radiation shall be considered. Other environmental hazards (see Section 7) shall also be considered.

If exposure of unprotected personnel to the primary or specularly reflected beam is possible, the LSO shall determine the irradiance or radiant exposure for the primary or specularly reflected beam or the radiance of an extended source at the location(s) of possible exposure.

3.3.1 Nominal Hazard Zones. Where applicable, e.g., in the presence of unenclosed Class 3B and Class 4 beam paths, the LSO will specify the Nominal Hazard Zone (NHZ).

If the beam of an unenclosed Class 3B or Class 4 laser or laser system is contained within a region having adequate control measures to protect personnel from exposure to levels of radiation above the appropriate MPE, that region may be considered to contain the NHZ. The NHZ may be determined by information supplied by the laser or laser system manufacturer, by measurement, or by using the appropriate laser range equation or other equivalent assessment.

The LSO shall assure that consideration is given to direct, reflected and scattered radiation in the establishment of boundaries for the laser controlled area. The LSO may declare the laser use area as the NHZ in lieu of calculating all possible NHZ distances, such as in the case of a dedicated laser use room.

Control measures are required within the NHZ and may fully enclose the NHZ when this area is limited in size (Section 4.3.10). Viewing the main beam or a specular laser target with an optical instrument is potentially hazardous due to the instrument's light-gathering capability (Section 4.3.5.2). Therefore, use of such optical systems may effectively increase the NHZ boundaries and must be considered in the overall hazard analysis.

3.4 Personnel.

The personnel who may be in the vicinity of a laser and its emitted beam(s), including maintenance personnel, service personnel, visitors and operators, can influence the total hazard evaluation and, hence, influence the decision to adopt additional control measures.

3.4.1 For lasers in a research setting, the principal hazard control rests with the operator, whose responsibility is to avoid aiming the laser at personnel or flat mirror-like surfaces.

Following are considerations regarding operating personnel and those who may be exposed:

- (1) Maturity of judgment of the laser user(s)
- (2) General level of safety training and experience of laser user(s).
- (3) Awareness of onlookers that potentially hazardous radiation may be present and awareness of the relevant safety precautions
- (4) Degree of training in laser safety of all individuals involved in laser operation.
- (5) Reliability of individuals to follow SOPs and recommended control procedures
- (6) Number/location of individuals relative to primary beam/reflections, and potential for accidental exposure
- (7) Other hazards not due to laser radiation which may cause the individuals to react unexpectedly or which influence the choice of personal protective equipment

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 laser devices during operation and maintenance.

The LSO shall have the authority to: monitor and enforce the control of laser hazards, and effect the knowledgeable evaluation and control of laser hazards (see Sections 1.3.2), and conduct surveillance of the appropriate control measures.

For all uses of lasers and laser systems, it is recommended that the minimum laser radiation required for the application be used.

Also, it is recommended that the beam height be maintained at a level other than the normal position of the eye of a person in the standing or seated positions.

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 the following conditions:

- (1) Unanticipated eye exposure during alignment
- (2) Misaligned optics and upwardly directed beams
- (3) Available eye protection not used
- (4) Equipment malfunction
- (5) Improper methods of handling high voltage
- (6) Intentional exposure of unprotected personnel
- (7) Operators unfamiliar with laser equipment
- (8) Lack of protection for non-beam hazards
- (9) Improper restoration of equipment following service
- (10) Eyewear worn not appropriate for laser in use
- (11) Unanticipated eye/skin exposure during laser usage
- (12) Inhalation of laser generated air contaminants / viewing laser generated plasmas
- (13) Fires resulting from the ignition of materials
- (14) Eye or skin injury of photochemical origin
- (15) Failure to follow standing operating procedures (SOPs)

A thorough understanding of the scope of laser hazards can facilitate the choice of appropriate / required control measures. This can be implemented with training program (Section 5).

Engineering controls (items incorporated into the system/designed into the installation) shall be given primary consideration in instituting a control measure program (Section 4.3).

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

If engineering controls are impractical or inadequate (Sections 4.1.1 and 4.1.2), administrative and procedural controls (Sections 4.4 and 4.5) and personal protective equipment (Section 4.6) 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 in developing a hazard control program.

Engineering, administrative, and procedural controls are summarized in Table 10.

4.1.1 Applicability of Control Measures. Purpose of control measures is to reduce possibility of human exposure to hazardous laser radiation (Section 3) and non-beam hazards (Section 7).

4.1.1.1 Operation, Maintenance, and Service. Important in the implementation of control measures is the distinction between the functions of *operation*, *maintenance*, and *service*.

First, systems are classified on the level of the laser radiation accessible during operation.

Operation is detailed in the user operation instructions.

Maintenance is a task specified in the maintenance instructions for assuring routine performance of the laser system. This may include such frequently required tasks as cleaning and replenishment of expendables. Maintenance may or may not require beam access.

Service is usually performed far less frequently than maintenance functions (may include replacing laser resonator mirrors or repairing components) and may require access to the laser beam. The functions are delineated in the service manuals of the laser system.

During 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 (Sections 4.3.12 and 4.4.7).

The fact that beam access is possible during maintenance or service procedures will *not alter* the classification of the laser system (based upon beam access conditions during operation.)

Instructions for the safe operation of laser systems are provided by the manufacturer. However, such instructions may not be sufficiently detailed for specific application due to special use conditions. In this case, the LSO shall provide additional safety instructions.

Note: The applicability of the various control measures as related to class is summarized in Table 10. The classes to which the following sections apply are designated in parentheses in the title of each section.

The control measures described in the following subparagraphs of this section shall apply

when a laser or laser system is in operation.

4.1.1.2 Supervised Laser Operation (Class 3B and 4). Class 3B and 4 laser systems shall be operated at all times 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 laser controlled area during all conditions of operation (Section 4.3.10).

4.1.1.3 Unattended Laser Operation (All Classes). Only Class 1 laser systems shall be used for unattended operation in unsupervised areas without the implementation of additional control measures requirements as detailed below. If a Class 1M, 2, 2M, or 3R laser system is not operated at all times under direct supervision or control of an experienced, trained operator, the laser system shall be provided with a clearly visible label that includes applicable information specified in Section 4.7.5.

If a Class 3B or 4 laser system is not operated at all times under the direct supervision or control of an experienced, trained operator, the laser radiation levels to which access can be gained 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 MPE limits in any space in the area that they may occupy.

The unattended use of Class 3B or 4 laser systems shall be permitted only when the LSO has implemented appropriate control measures that provide adequate protection and laser safety training to those who may enter the laser controlled area during unattended use.

All areas where unattended Class 3B or 4 laser systems operate shall be provided with standard laser safety warning area signs containing the "Danger" signal word and appropriate instructions regarding the hazards of entry, when no operator is present (Section 4.7.4).

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 which has been modified. However, one should note that lasers and laser systems which have been altered may necessitate recertification, reclassification, and compliance reporting under the requirements of the Federal Laser Product Performance Standard (FLPPS).

4.1.4 Electrical, Beam Interaction, and Other Associated Hazards. See Section 7.

4.1.5 Laser Pointers. Users of laser pointers in AU facilities need to be aware of the potential hazards, and are required to follow the recommended safety procedures provided by the manufacturer. Users of these products in AU facilities are responsible for their safe usage. It is recommended that the power of a laser pointer should not exceed 1 mW.

The FDA includes laser pointers under the definition of a surveying, leveling, and alignment laser products. This is included in the U.S. Federal Laser Product Performance Standard (21 CFR Part 1040.11) for Specific Purpose Laser Products (latest revision). That section indicates that each such laser product shall comply with all of the applicable requirements of 1040.10 for a Class I, II, or IIIA laser product and shall not permit human access to laser radiation in excess of the accessible emission limits of Class I and, if applicable, Class II, or Class IIIA (CDRH classifications). Hence, by this definition, laser pointers are technically limited to the maximum Class 3R (5 mW) output.

Note: The FDA has issued a warning to parents and school officials about the possibility of eye damage to children from hand-held laser pointers which indicated that such devices are generally safe when used as intended by teachers and lecturers to highlight areas on a chart or screen. However, they are not to be considered as children's toys. They note that the light energy that laser pointers can aim into the eye can be more damaging than staring directly into the sun. Federal law requires a warning on the product label about this potential hazard to the eyes and the FDA suggests they should be used by children only with adequate supervision (www.fda.gov/bbs/topics/NEWS/NEW00609.html).

It is of importance that users be aware that some communities have adopted local ordinances which impose limitations on laser pointer use and/or purchase.

4.2 Substitution of Alternate Control Measures (Class 3B or 4).

Upon review and approval by the LSO, the engineering control measures specified in 4.3 and administrative controls specified in Section 4.4 for Class 3B and 4 laser systems, may be replaced by procedural, administrative (Section 4.4), or other alternate engineering controls which provide equivalent protection.

If alternate control measures are instituted, then those personnel directly affected by the measures shall be provided appropriate safety/operational training (Sections 5 and 7).

4.3 Engineering Controls.

Engineering controls are specified in Sections 4.3.1-4.3.14 and summarized in Table 10. Commercial laser products manufactured in compliance with the Federal Laser Product Performance Standard (FLPPS) will be certified by the manufacturer and will incorporate those engineering controls required by the FLPPS or the IEC 60825-1 standard (or latest revision thereof). The LSO shall affect any additional engineering control measures that are required as outlined in Section 4.

The use of the additional controls section shall be considered in order to reduce the potential for hazard associated with some applications of laser systems.

Engineering controls are: supplied by the manufacturer of certified products and, used in this document are described in Sections 4.3.1, 4.3.2, 4.3.3, 4.3.4, 4.3.5.1, 4.3.7, 4.3.8, 4.3.14.

4.3.1 Protective Housings (All Classes). Protective housing shall be provided for all classes of laser systems (exceptions noted in Section 4.3.1.1). Protective housing may require interlocks (Section 4.3.2) / labels (Section 4.7). See ANSI Z136.1-2007 for further details.

4.3.1.1 Operating a Laser without Protective Housing (Class 3B or 4). In some circumstances, such as research and development and during the manufacture or servicing of lasers, operation of lasers systems without a protective housing may become necessary. In such cases, the LSO shall affect a hazard analysis and ensure that control measures are instituted appropriate to the class of maximum accessible emission level to assure safe operation. See ANSI Z136.1-2007 for further details.

4.3.1.2 Walk-in Protective Housing (Embedded Class 3B or 4). Class 1 laser systems containing embedded Class 3B or 4 lasers with protective housings of sufficient size to allow personnel within the working space (walk-in protective housings), shall be provided with an area warning system (floor mats, IR sensors, etc.) which is activated upon entry by personnel into the protective housing. See ANSI Z136.1-2007 for further details.

Note: Engineering controls are preferred over administrative controls.

4.3.2 Interlocks on Removable Protective Housings (All Classes with Embedded Class 3B or 4). Protective housings which enclose Class 3B or 4 laser systems shall be provided with an interlock system which is activated when the protective housing is opened or removed during operation / maintenance. Interlock system shall be designed to prevent access to laser radiation above the applicable MPE. It may, for example, be electrically or mechanically interfaced to a shutter which interrupts the beam when the protective housing is opened or removed (see Section 7.2 for electrical hazards).

Fail-safe interlocks shall be provided for any portion of the protective housing which, by design, can be removed or displaced during operation and maintenance, and thereby allows access to Class 3B or 4 laser radiation. One method to fulfill the fail-safe requirement is the use of redundant electrical series connected interlocks. See ANSI Z136.1-2007 for details.

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

- (1) Be interlocked (fail-safe interlock not required), or
- (2) Require a tool for removal and shall have an appropriate warning label (Section 4.7) on the panel.

4.3.4 Key Control (Class 3B or 4). A Class 3B or 4 laser system shall be provided with a master switch. This switch shall effect beam termination or system shutoff and shall be operated by a key, or by a coded access (such as a computer code). The authority for access to the master switch shall be vested in the appropriate supervisory personnel. See ANSI Z136.1-2007 for further details.

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

4.3.5.1 Viewing Windows and Diffuse Display Screens (All Classes). All viewing windows / diffuse (reflective / transmitted) display screens included as an integral part of a laser system, shall incorporate a suitable means (interlocks, filters, attenuators) to maintain the laser radiation at the viewing position at or below the applicable MPE (see Section 4.6.2.5.2).

4.3.5.2 Collecting Optics (All Classes). All collecting optics (telescopes, microscopes, endoscopes, eye-loupes, lenses, etc.) that integrate the use of a laser system shall incorporate suitable means (interlocks, filters, attenuators) to maintain the radiation transmitted through the collecting optics to levels at or below the appropriate MPE (Section 4.6.2.5.2). Collecting optics filter housings shall be labeled in accordance with Section 4.6.5.3.

Note: Normal or prescription eyewear, are not considered collecting optics.

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

4.3.6.1 Fully Open Beam Path (Class 3B or 4). In applications of Class 3B or 4 laser systems, where a beam path is unenclosed, a hazard evaluation shall be effected by the LSO, who shall establish controls appropriate with magnitude/extent of accessible radiation.

4.3.6.2 Limited Open Beam Path (Class 3B or 4). In applications of Class 3B or 4 laser systems, where the beam path is confined by design to significantly limit the degree of accessibility of the open beam, a hazard analysis shall be affected by the LSO. This shall establish controls appropriate to the magnitude and extent of the accessible radiation.

4.3.6.2.1 Class 1 Conditions. 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 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 MPE levels.

4.3.6.3 Enclosed Beam Path (All Classes). In applications of lasers or laser systems where the entire beam path is enclosed, and the enclosure fulfills all requirements of a protective housing (i.e., limits the laser radiation exposure at or below the applicable MPE; see Sections 4.3.1 and 4.3.2), the requirements of Class 1 are fulfilled and no further controls are required. When the protective housing requirements are temporarily relaxed, such as during service, the LSO shall affect the appropriate controls. These may include a temporary laser control area (Section 4.3.12) and administrative and procedural controls (Section 4.4).

Protective housings which are of sufficient size to allow personnel within the enclosure (walk-in protective housings) require special interlocking (Section 4.3.1.2).

4.3.7 Remote Interlock Connector (Class 3B or 4). A Class 3B laser system should and Class 4 laser system shall, be provided with a remote interlock connector. This connector facilitates electrical connections to an emergency master disconnect interlock, or a room, entryway, floor, or area interlock, as may be required. (Section 4.3.10.2).

When the terminals of the connector are open-circuited, the accessible radiation shall not exceed the applicable MPE.

4.3.8 Beam Stop / Attenuator (Class 3B or 4). Class 3B laser systems should be provided with a permanently attached beam stop or attenuator (Table 10).

Class 4 laser systems shall be provided with a permanently attached beam stop or attenuator. The beam stop / attenuator shall be capable of preventing access to radiation in excess of the

applicable MPE when the laser system output is not required, as in warm up procedures. There may be a few instances, during service, 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. In this case, the LSO may deem that laser eye protection is not required.

Note: For those lasers or laser systems that do not require a warm-up time, the main power switch may be substituted for the requirement of a beam stop or attenuator.

4.3.9 Laser Area Warning Signs / Activation Warnings (Class 3R, 3B, or 4).

4.3.9.1 Warning Signs – Posting (Class 3R, 3B or 4).

Class 3R Laser Area: An area which contains a Class 3R laser or laser system should be posted with the appropriate sign as described in Section 4.7, except as excluded by Sections 4.5.1.10 and 4.1.5 (laser pointer).

Class 3B or 4 Laser Area: An area which contains a Class 3B or 4 laser system shall be posted as described in Sections 4.3.10.1, 4.3.10.2, and 4.3.11.1 with the appropriate sign described in Section 4.7, except as excluded by Section 4.5.1.10.

Temporary Laser Controlled Area (Class 3B and 4): The exterior boundary of a temporary laser controlled area (Section 4.3.12) shall be posted with a Notice sign as described in Section 4.7, and as detailed in Section 4.7.3.3.

4.3.9.2 Warning Signs – Purpose (Class 3R, 3B, or 4). The purpose of a laser area warning sign is to convey a rapid visual hazard-alerting message that:

- (1) Warns of the presence of a laser hazard in the area
- (2) Indicates specific policy in effect relative to laser controls
- (3) Indicates the severity of the hazard (e.g., class of laser, NHZ extent, etc.)
- (4) Instructs appropriate action to reduce the hazard (eyewear requirements, etc.)

Laser warning signs shall utilize warning statements, where the signal word meanings are:

“**DANGER**” indicates an imminently hazardous situation which, if not avoided, will result in death or serious injury. This signal word is 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 relates to the safety of personnel or the protection of property. This word shall not be associated directly with a hazard / hazardous situation and must not be used in place of “DANGER” or “CAUTION”.

4.3.9.3 Warning Signs for Non-Beam Hazards. Warning signs for non-beam hazards (e.g., LGAC's, electrical, compressed gases) as detailed in Section 7, shall be posted when the hazards are possible as specified in the current revision of ANSI 535.2 (see Multiple Hazard Labeling Requirements) and/or other standards applicable to the specific hazard(s).

4.3.9.4 Activation Warning Systems (Class 3B or 4). Activation warning system should be used with Class 3B, and shall be used with Class 4 laser systems during activation or startup.

4.3.9.4.1 Audible Warning Devices (Class 3B and 4). For single-pulse laser systems, an audible system may commence operation when the power supply is charged for operation, for example, during the charging of capacitor banks. Note that distinctive/clearly identifiable sounds arising from auxiliary equipment (vacuum pump or fan) and which are uniquely associated with emission of energy are also acceptable as audible warnings.

4.3.9.4.2 Visible Warning Devices (Class 3B and 4). A form of visible warning is: a single red light/lighted laser sign that flashes during operation, is readably visible with protective eyewear and, viewable within the area. Light can be interfaced/controlled by the power supply so it is on/flashing only when the laser is operating.

Another form can be a warning light assembly interfaced to the laser controller indicating: enabled laser (high voltage on), laser on (beam on), and area clear (no high voltage or beam on). (*Note: 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.

Note: The LSO shall consider alternative control measures for hearing / visually impaired.

4.3.10 Indoor Laser Controlled Area (Class 3B or 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, a laser controlled area shall be established and adequate control measures instituted (see Section 4.3.10.1 or 4.3.10.2).

Note: Contact the LSO for requirements for laser systems involving the general public.

4.3.10.1 Class 3B Indoor Laser Controlled Area (Class 3B). 3B controlled area shall:

- (1) Be controlled to permit laser systems to be operated only by personnel trained in laser safety and in the operation of the laser or laser system. (See Section 5.5).
- (2) Be posted with the appropriate warning signs (see Section 4.7), except as detailed in Section 4.5.1.10. Appropriate warning sign shall be posted at the entryways and, if deemed necessary by the LSO, should be posted within the laser-controlled area.
- (3) Be operated in a manner such that the path is well defined
- (4) Be defined/controlled if beam extends outdoors/projects into a controlled airspace, especially under adverse atmospheric conditions (Section 4.3.11.1/ 4.3.11.2).

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

- (5) Be under the direct supervision of an individual knowledgeable in laser safety
- (6) Be located so spectator access is limited/requires approval. (exceptions Section 4.5
- (7) Have potentially hazardous beam terminated by an appropriate beamstop.
- (8) Have only diffusely reflecting materials in or near the beam path, where feasible
- (9) Provide personnel within the laser-controlled area with the appropriate eye protection as specified in Section 4.6
- (10) 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, except as required for medical use
- (11) Have all windows, doorways, open portals, etc. 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
- (12) Require storage or disabling (for example, removal of the key) of the laser or laser system when not in use to prevent unauthorized use

4.3.10.2 Class 4 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 requiring entry into a laser controlled area shall: be appropriately trained, provided with protective equipment, and follow all applicable administrative/procedural controls (Section 5). For requirements for spectators, see Section 4.4.6.

4.3.10.2.1 Emergency Conditions. For emergency conditions there shall be a clearly marked "Emergency Stop" or other appropriately marked device appropriate for the intended purpose (remote controlled connector or equivalent device) available for deactivating the laser or reducing the output to levels at or below the applicable MPE.

4.3.10.2.2 Entryway Controls. Class 4 laser controlled area shall be designed to fulfill items of Section 4.3.10.1 and in addition shall incorporate one of the following alternatives:

- (1) Non-defeatable (non-override) Area or Entryway Safety Controls.
Shall be used to deactivate laser or reduce output to levels at or below MPE in event of unexpected entry into the controlled area (Figure 2a).
- (2) Defeatable Area or Entryway Safety Controls.
Shall be used if non-defeatable area/entryway safety controls limit the intended use of the laser system. For example, during normal usage requiring operation without interruption, 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 adequately trained and provided with adequate personal protective equipment (Figure 2a).

(3) Procedural Area or Entryway Safety Controls.

If safety latches/interlocks are infeasible/inappropriate: apply the following (Fig 2b):

- (a) All authorized personnel shall be adequately trained and adequate personal protective equipment shall be provided upon entry.
- (b) A door, blocking barrier, screen, curtains, etc. shall be used to block, screen, or attenuate the laser radiation at the entryway. The level of laser radiation at the exterior of these devices shall not exceed the applicable MPE, nor shall personnel experience any exposure above the MPE immediately upon entry.
- (c) At the entryway there shall be an activation warning system indicating that the laser is energized and operating at Class 4 levels (see 4.3.9.4).

4.3.11 Outdoor Control Measures (All Classes).

4.3.11.1 General. For outdoor laser operations, see the LSO and ANSI Z136.1-2007.

4.3.11.2 Use of Lasers in Navigable Airspace (All Classes). The Federal Aviation Administration (FAA) is responsible for regulating the use and 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 laser systems in navigable airspace should be coordinated with the FAA (Washington, DC 20590 / any FAA regional office) and U.S. Space Command (consult the current ANSI Z 136.6) in the planning stages to ensure proper control of any attendant hazard to airborne personnel or equipment. Also refer to FAA Order 7400.2 (or latest revision thereof) and ANSI Z1 3 6.6-2005 (or latest revision thereof). Laser light show demonstrations that use Class 3B or Class 4 laser systems to create visible open beams shall coordinate with the FDA prior to use (See 4.5.1).

4.3.12 Temporary Laser Controlled Area (All Classes). In conditions where removal of panels/protective housings, overriding protective housing interlocks, or entry into NHZ becomes necessary (for service), and accessible laser radiation exceeds the MPE, a temporary laser controlled area shall be devised for the laser system. Such an area, which will not have the built-in features as defined for a laser controlled area, shall provide all safety requirements for all personnel, within and outside the area. A Notice sign (Section 4.7.3.3) shall be posted outside the temporary laser controlled area to warn of the potential hazard.

4.3.13 Controlled Operation (Class 4). Whenever appropriate and possible, Class 4 lasers or laser systems should be controlled and monitored at a position as distant as possible from the emission portal of the laser or laser system.

4.3.14 Equipment Labels (All Classes) *Note: Labeling of laser equipment in accordance with the Federal Laser Product Performance Standard (FLPPS) or the IEC 60825-1 standard (or latest revision thereof) may be used to satisfy the equipment labeling requirements in this standard.*

4.3.14.1 Warning Logotype Label for Equipment (All Classes Except Class 1). All laser systems (except Class 1) shall have appropriate warning labels (Section 4.7.5) with the laser sunburst logotype symbol and appropriate cautionary statement. Label shall be affixed to a conspicuous place on the laser housing or control panel. Such labels should be placed on both the housing and the control panel if these are separated by more than 2 meters.

4.3.14.2 Protective Housing Equipment Label (All Classes). Advisory housing labels indicating relative radiation hazard contained within shall be placed on all removable housings with no safety interlock and which can be removed / displaced during operation, maintenance, or service, and thus allows access to laser radiation in excess of the MPE. Laser sunburst logotype symbol is not required on such labels. (Section 4.7.5 (1)(a-e))

4.3.14.3 Long Distance Beam Conduit Label (All Except Class 1). LSO shall effect posting advisory protective housing labeling on long distance (>3 meters) beam conduits containing > Class 1 levels. Label shall be placed outside conduit at intervals (~ 3 meters), to provide warning of the relative hazards of radiation contained in the conduit. The sunburst logotype symbol is not required on such advisory housing labels. (Section 4.7.5 (1)(a-e)).

Note: This does not apply to optical fiber cable used for telecommunications. See ANSI Z136.2-1997 or IEC 60825-2 (or latest revision thereof) for OFCS labeling requirements.

4.4 Administrative and Procedural Controls

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

The administrative and procedural controls are summarized in Table 10.

4.4.1 Standard Operating Procedures (Class 3B or 4). The LSO shall require and approve written SOPs for Class 3B and Class 4 lasers or laser systems. These written SOPs shall be maintained with the laser equipment for reference by the operator, and maintenance or service personnel (Section 4.4.5).

4.4.2 Output Emission Limitations (Class 3R, 3B, or 4). If, in the opinion of the LSO, excessive power/radiant energy is accessible during operation/maintenance of a Class 3R, 3B, or 4 laser systems, the LSO shall take such action as required to reduce the levels of accessible power or radiant energy to that which is commensurate with the required application.

4.4.3 Education and Training (All Classes except Class 1). Education and training shall be provided for operators/maintenance/service personnel for Class 3B or 4 laser systems. Education and training should be provided for operators/maintenance/service personnel of Class 1M, 2, 2M, and 3R. Level of training shall be commensurate with level of hazard.

4.4.4 Authorized Personnel (Class 3B or 4 or Embedded Class 3B or 4). Class 3B or 4 laser systems shall be operated, maintained, or serviced only by authorized personnel. Laser systems with enclosed Class 3B or 4 lasers shall be maintained/ serviced only by authorized personnel if such procedures would permit access to levels which exceed the Class 3R AEL.

4.4.5 Alignment Procedures (All Classes except Class 1). Incident reports have repeatedly shown that an ocular hazard may exist during beam alignment procedures. Alignment of Class 2, 3R, 3B, or 4 laser optical systems, shall be performed in such a manner that the primary beam, or specular, or diffuse reflection of a beam, does not expose the eye to a level above the applicable MPE (Section 4.6.2.5.2(3)).

There are many instances 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 methods shall be approved for Class 3B and 4 laser systems. SOPs shall also be applicable for all classes of lasers which contain embedded Class 3B or 4 lasers under conditions which would allow access during 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 or Class 4 visible or invisible lasers and laser systems.

4.4.5.1 Alignment Procedures for Class 3B and 4 Lasers

Alignments should be done only by those who have received laser safety training. In addition, the following actions should be taken:

- (1) Exclude unnecessary personnel from the laser area during alignment.
- (2) Whenever possible, use low-power visible lasers for path simulation of higher-power visible or invisible lasers.
- (3) 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.
- (4) Perform alignment tasks for high-power lasers, at lowest possible power level.
- (5) Use a shutter/beam block, to block high-power beams at their source except when actually needed during the alignment process.
- (6) Use a laser-rated beam block to terminate high-power beams down range of the optics being aligned.
- (7) Use beam blocks and/or laser protective barriers in conditions where alignment beams could stray into areas with uninvolved personnel.

- (8) Place beam blocks behind optics (turning mirrors) to terminate beams that might miss mirrors during alignment.
- (9) Locate/block stray reflections before going to next optical component/section.
- (10) Be sure all beams/reflections are properly terminated before hi-power operation.
- (11) Post appropriate area warning signs during alignment procedures where lasers are normally Class 1 (enclosed). Section 4.3.12.

4.4.6 Spectators (Class 3B or 4). Spectators should not be permitted in a laser control area (Sections 4.3.10 and 4.3.11) which contains a Class 3B laser system and spectators shall not be permitted in a laser control area which contains a Class 4 laser system, unless:

- (1) Appropriate approval from the supervisor has been obtained;
- (2) The degree of hazard and avoidance procedure has been explained; and
- (3) Appropriate protective measures are taken.

4.4.7 Service Personnel (All Classes). Personnel who require access to Class 3B or 4 laser systems enclosed within a protective housing / protected area enclosure shall comply with the appropriate control measures of the enclosed / embedded laser system. LSO shall confirm service personnel have the education / safety training commensurate with the class of the laser system contained within the protective housing.

4.5 Special Considerations.

4.5.1 Laser Demonstrations Involving the General Public. Contact the LSO if you wish to conduct a laser demonstration involving the general public.

4.5.1.1 Federal, State, or Local Requirements. The laser operator responsible for producing the demonstration shall ensure that all federal, state, or local requirements are satisfied.

4.5.2 Laser Optical Fiber Transmission Systems (All Classes). Laser transmission systems which employ optical cables shall be considered enclosed systems with the optical cable forming part of the enclosure.

4.5.2.1 Connection/disconnection during operation, maintenance, modification, or service shall take place in appropriate laser controlled area, in accordance with Section 4.3.12.

Optical fibers/optical fiber cables attached to Class 3B or 4 laser systems shall not be disconnected prior to termination of transmission of the beam into the fiber.

It is recommended that procedures be instituted to prevent inadvertent personnel exposure from an un-terminated or severed fiber, such as lockout/tag out requirements at the laser source.

When the connection or disconnection is made within a secured enclosure, no tool for connector disconnection shall be required, but a warning sign appropriate to the class of laser or laser system shall be visible when the enclosure is open.

4.6 Protective Equipment.

4.6.1 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 MPE, it may be necessary to use personal protective equipment such as: goggles / spectacles; barriers / windows; clothing / gloves, and other devices selected for suitable protection against laser radiation. It should be noted that personal protective equipment may have serious limitations when used as the only control measure with higher-power 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.

4.6.2 Protective Eyewear (Class 3B or 4).

4.6.2.1 Eye Protection (Class 3B or 4). Eye protection devices which are designed for protection against radiation from Class 3B or 4 laser systems shall be administratively required within the NHZ and their use enforced when engineering / procedural / administrative controls are inadequate to eliminate potential exposure in excess of the MPE. Contact LSO for

information / assistance in selection of appropriate laser safety eyewear. A copy of the Laser Institute of America "Guide for the Selection of Laser Eye Protection" is available at the Radiation Safety Office in room 201, Leach Science Center. Protective eyewear is usually not required for Class 2 or 3R laser systems except in conditions where intentional long-term (> 0.25 s) direct viewing is required. Protective eyewear may include goggles, face shields, spectacles, or prescription eyewear using special filter materials or reflective coatings (or a combination of both) to reduce the potential ocular exposure below the MPE. Laser protective eyewear shall be specifically selected to withstand either direct or diffusely scattered beams depending upon the anticipated circumstances of exposure. The eyewear shall be used in a manner so 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.

4.6.2.2 UV Laser Protection. Particular care shall be taken when using UV laser systems. So, in addition to other controls which apply to all laser systems, the following requirements shall also apply. Exposure to UV radiation shall be minimized by using beam shields and clothing which attenuate the radiation to levels below the MPE for the specific UV wavelengths. Hazardous byproducts: 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, LGAC's, etc. (Section 7.4).

Personal Protective Equipment (PPE), shall be used when working with open beam Class 3B or 4 UV lasers. This shall include both eye and skin protection.

4.6.2.3 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.

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

- (1) Laser power and/or pulse energy
- (2) Wavelength(s) of laser output
- (3) Potential for multi-wavelength operation
- (4) Radiant exposure or irradiance levels for which protection (worst case) is required
- (5) Exposure time criteria (Section 4.6.2.5.2)
- (6) Maximum permissible exposure (MPE) (Section 8)
- (7) Optical density requirement of eyewear filters at output wavelengths (Table 2)
- (8) Angular dependence of protection afforded
- (9) Visible light transmission requirement and assessment of the effect of the eyewear on the ability to perform tasks while wearing the eyewear
- (10) Need for side-shield protection and maximum peripheral vision requirement; side shields shall be considered and should be incorporated where appropriate
- (11) Radiant exposure/irradiance and corresponding time factors at which filter change occurs, including transient bleaching especially for ultrashort pulse lengths
- (12) Need for prescription glasses
- (13) Comfort and fit
- (14) Degradation of filter media, such as photobleaching
- (15) Strength of materials (resistance to trauma/shock) (ANSI Z87. 1-2003)
- (16) Capability of the front surface to produce a hazardous specular reflection
- (17) Requirement for anti-fogging design or coatings

4.6.2.5 Optical Density.

4.6.2.5.1 Specification of Optical Density, OD. The optical density of laser eyewear at a specific wavelength shall be specified. Many lasers radiate at more than one wavelength; thus eyewear with an adequate OD at a particular wavelength may have a completely inadequate OD at another wavelength radiated by the same laser. This problem becomes particularly serious with lasers that are tunable over broad wavelengths. In such cases, alternative methods may be more appropriate (image converters, closed circuit TV). The OD of the

protective material shall be determined for all anticipated viewing angles and wavelengths.

4.6.2.5.2 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 optical density of a filter material (Tables 2 and 4). The following are recommendations that are applicable in determining the time factor criteria:

- (1) **Aversion Response Criteria to Visible Lasers (0.4-0.7 m) (Class 3B or 4).** When long-term intrabeam exposure to visible lasers is not intended, the applicable MPE used to establish the optical density requirement for eye protection should be based on an exposure time of 0.25 second (Section 8.2 and Table 4). This time factor is based upon the human aversion time for a bright light stimulus. Thus, this becomes the "first line of defense" for unexpected exposure to some lasers (see Section 8.2.2).
- (2) **Near infrared Criteria (Class 3B or 4).** When long-term exposure to point source, near infrared (0.7-1.4 m) lasers is not intended, the applicable MPE used to establish the optical density requirement for eye protection should be based on a 10 second exposure (see Section 8.2.2). This represents a realistic "worst case" time period because natural eye motions dominate for periods longer than 10 s.
- (3) **Diffuse Viewing Criteria (Class 3B or 4).** When viewing an extended source or the diffuse reflection of the beam from a Class 3B or 4 laser system where intermediate viewing time is intended, optical alignment procedures, the MPE should be based upon the maximum viewing time which may be required during any given 8 hour period. When long-term exposure to visible (0.4-0.7 m) CW lasers is not specifically intended, the applicable MPE used to establish the optical density requirement for eye protection may be based on a 600-second 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.
- (4) **Daily Occupational Exposure Criteria (Class 3B or 4).** The time period of 30,000 seconds represents a full one-day (8-hour) occupational exposure determined from the approximate number of seconds in an 8 hours. When long-term exposure is possible, the MPE used to establish OD requirement shall be based on a 30,000 sec exposure.

4.6.2.6 Visible Transmission. Adequate optical density, at the laser wavelength of interest shall be weighed with the need for adequate visible transmission.

4.6.2.7 Identification of Eyewear. All laser protective eyewear shall be clearly labeled with the optical density/wavelength for which protection is afforded (Section 4.6.2.5). Color coding/distinctive identification of eyewear is recommended in multi-laser environments.

4.6.2.8 Cleaning and Inspection. Periodic cleaning and inspection shall be made of protective eyewear to ensure the maintenance of satisfactory condition. The frequency of the inspection should be once per year. This shall include:

- (1) Periodic cleaning of laser eyewear. Care should be observed when cleaning lenses to avoid damage to the absorbing/reflecting surfaces. Consult eyewear manufacturers for instructions for proper cleaning methods.
- (2) Inspect the attenuation material for pitting, crazing, cracking, discoloration, etc.
- (3) Inspect the frame for mechanical integrity.
- (4) Inspect for light leaks and coating damage.

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

4.6.2.9 Purchasing Information for Protective Eyewear. Purchasers of laser safety protective eyewear should require that the following information accompanies each item:

- (1) Wavelength(s) and corresponding optical density for which protection is afforded;
- (2) Pertinent data such as damage threshold for laser safety purposes; and
- (3) Manufacturers' recommendations on shelf life, storage conditions, cleaning and use.

4.6.3 Facility Window Protection (Class 3B or 4). Facility windows (exterior/interior) located within the NHZ of a Class 3B or 4 laser system shall be provided with an appropriate absorbing filter, scattering filter, blocking barrier, or screen which reduces any transmitted laser

radiation to levels below the applicable MPE. See ANSI Z136.1-2007 for further details.

4.6.4 Laser Protective Barriers or Curtains (Class 3B or 4). A blocking barrier, screen, or curtain which can block/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 MPE. In some cases, if the barrier does not extend completely to ceiling or the floor, the LSO shall conduct an NHZ analysis to assure safety is afforded to all workers outside the barrier protected area. See ANSI Z136.1-2007 for further details.

4.6.5 Labeling of Protective Equipment (Class 3B or 4). Protective equipment shall be permanently labeled as specified below:

4.6.5.1 Labeling of Laser Protective Eyewear. Protective eyewear shall be labeled with the optical density and wavelength(s) for which protection is afforded (Section 4.6.2.4).

4.6.5.2 Labeling of Laser Protective Windows. Protective windows shall be labeled with the OD and wavelengths for which protection is afforded (Section 4.6.2.4).

4.6.5.3 Labeling of Collecting Optics Filters. Permanently mounted collecting optics housings containing protective filters shall be labeled with the OD and wavelengths for which protection is afforded (Section 4.6.2.5). These filter housings should also be labeled with the threshold limit (TL)/exposure time for which applies and conditions which afford protection.

4.6.5.4 Labeling of Laser Protective Barriers. Protective barriers shall be labeled with the applicable exposure time and the beam exposure conditions which provide protection.

4.6.5.5 Labeling of Laser Protective Viewports and Films. Viewports/films should be labeled with the OD and spectral region providing protection. Provided by the manufacturer.

4.6.6 Skin Protection (Class 3B or 4). In some applications (excimer lasers operated in UV) the use of a skin cover shall be employed if exposures are anticipated at levels at/near the skin MPE. Skin protection is best achieved through engineering controls. If the potential exists for a skin exposure, particularly for UV lasers, skin-covers/sunscreen are recommended. Most gloves provide some protection against laser radiation. Tightly woven fabrics/opaque gloves provide the best protection. A laboratory coat may fulfill the requirement.

For Class 4 lasers, consideration shall be given to flame-retardant materials.

4.6.7 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).

4.7 Area Warning Signs and Equipment Labels.

4.7.1 Design of Signs. Sign dimensions, letter size & color, etc., shall be in accordance with American National Standard for Accident Prevention Signs, ANSI Z535 series. Figures 1a and 1b show sample signs for Class 2, 2M, 3R, 3B, and 4 laser systems.

4.7.2 Symbols. Two similar laser symbol designs are accepted for laser signs and labels.

4.7.2.1 Laser Symbol Design. There are two possible designs that can be used:

4.7.2.1.1 ANSI Z535 Design. The laser hazard symbol shall be a sunburst pattern with two sets of radial spokes of different lengths and one long spoke, radiating from a common center. Wording can be used for area warning signs only, or as specified in Section 4.7.3.

4.7.2.1.2 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 spoke, radiating from a common center (Fig 1c).

4.7.2.2 Safety Alert Symbol. Symbol indicating a potential personal safety hazard. It is composed of an equilateral triangle surrounding an exclamation mark. To be located left of the signal word on the "Danger" or "Caution" signs. It is not used on the "Notice" signs.

4.7.3 Signal-Words Laser Warning Signs—Purpose (Class 3R, 3B, or 4). The purpose of a laser area warning sign is to convey a rapid visual hazard-alerting message that:

- (1) Warns of the presence of a laser hazard in the area

- (2) Indicates specific policy in effect relative to laser controls
- (3) Indicates the severity of the hazard (e.g., class of laser, NHZ extent, etc.)
- (4) Instructs appropriate action to take to avoid the hazard (eyewear requirements, etc.)

The signs shall utilize warning statements where the words have the following meanings:

“**DANGER**” indicates an imminently hazardous situation which, if not avoided, will result in death/serious injury. This 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 to the safety of personnel/the protection of property. This word shall not be associated directly with a hazard/hazardous situation and not be used in place of “**DANGER**” or “**CAUTION**”.

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

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

4.7.3.2 Caution. The word “Caution” shall be used with all signs and labels associated with Class 2 and 2M laser systems, which do not exceed the MPE (Figure 1 a).

4.7.3.3 Notice. The word “Notice” shall be used on signs posted outside a temporary laser controlled area (Sections 4.3.12 / 4.3.9.2), i.e., during periods of service (Figure 1d).

Note: when a temporary laser controlled area is created, the area outside the temporary area remains Class 1, while the area within is either Class 3B or 4 and appropriate danger warning is required within the temporary laser controlled area (Figure 1b / Section 4.3.12).

4.7.4 Pertinent Sign Information. Information / warnings shall conform to the following:

4.7.4.1 The appropriate word (Danger, Caution, or Notice) shall be located in upper panel.

4.7.4.2 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:

- (1) At position 1 above the tail of the sunburst, special precautionary instructions or protective action that may be applicable. For example:
 - (a) Laser Protective Eyewear Required
 - (b) Invisible Laser Radiation
 - (c) Knock Before Entering
 - (d) Do Not Enter When Light is On
 - (e) Restricted Area

Note: The class-based warning descriptions given in Section 4.7.5 (1) (a-e) can alternatively be used in position 1.

- (2) At position 2 below the tail of the sunburst, the type of laser (Nd:YAG, He-Ne, etc.), or the emitted wavelength, pulse duration (if appropriate), and maximum output; and

- (3) At position 3, the class of the laser or laser system.

Note: The word “Radiation” on signs/labels may be replaced by the word “Light” for lasers operating in the visible range ($> 0.4 \text{ m}$ and $\leq 0.7 \text{ m}$). Lasers operating outside this visible range the word “Invisible” shall be placed prior to “Laser Radiation.”

4.7.4.3 Sign Location. Shall be displayed where they will serve to warn onlookers.

4.7.5 Pertinent Equipment Label Information. Label shall conform to the following:

- (1) At position 1 above the tail of the sunburst, special precautionary instructions or protective actions required by the reader such as:
 - (a) For Class 2 laser systems, “Laser Radiation - Do Not Stare into Beam”
 - (b) For Class 2M and 3R lasers systems where the accessible irradiance does not exceed the MPE based upon a 0.25 s exposure for wavelengths between 0.4 and 0.7 m (Section 3.3.3.1), “Laser Radiation – Do Not Stare into Beam or View Directly with Optical Instruments”

- (c) For other Class 3R laser systems, “Laser Radiation – Avoid Direct Eye Exposure”
- (d) For Class 3B laser sys., “Laser Radiation – Avoid Direct Exposure to Beam”
- (e) For Class 4 laser systems, “Laser Radiation – Avoid Eye or Skin Exposure to Direct or Scattered Radiation”

Note: Labeling of laser equipment in accordance with the Federal Laser Product Performance Standard (FLPPS) or the IEC 60825-1 standard may be used to satisfy the labeling requirements in this manual.

- (2) At position 2 below the tail of the sunburst, type of laser (Nd:YAG, He-Ne, etc.), or the emitted wavelength, pulse duration (if appropriate), and maximum output; and
- (3) At position 3, the class of the laser or laser system.

4.7.5.1 Location of Equipment Labels. Labels shall be conspicuously displayed in locations on the equipment where they best will serve to warn onlookers (Section 4.3.14).

5. Education and Training

5.1 General.

Training shall be provided to each employee routinely working with or potentially exposed to Class 3B or 4 laser radiation. Training should be provided to employees working with or potentially exposed to Class 1M, 2, 2M or 3R laser radiation. Level of training shall be commensurate with degree of potential laser hazards, both from laser radiation and non-beam hazards. The course topics selected from Appendix D, and the depth and skill level of content, shall largely be determined based on the results from a complete hazard evaluation.

5.2 User Training.

All Auburn University staff and students operating or working in the vicinity of Class 3B or 4 laser systems are required to take the Laser Safety training offered by RMS. Training shall be provided to users of Class 1M, 2, 2M and 3R lasers by the appropriate PI/laser supervisor. The training shall include warnings against the misuse of lasers.

Laser safety training shall be provided to the users of Class 3B or 4 lasers systems.

Users shall include operators, technicians, engineers, maintenance and service personnel, and any persons working with or potentially exposed to laser radiation in excess of Class 1. The training shall ensure that the users are knowledgeable of potential hazards and control measures for laser equipment they may have occasion to use. All training shall be commensurate with the greatest potential for hazards associated with each laser operation, and shall be consistent with results of the completed hazard evaluation as performed by the LSO, which considers the laser, the environment, and the personnel. Where appropriate, training shall include cardiopulmonary resuscitation (CPR) and safety procedures for applicable non-beam hazards (Section 7) associated with laser systems in use.

6. Medical Examinations

6.1 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 and exposure situation to assure appropriate medical referral. See Appendix E for recommended examination protocol 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.

6.2 Medical Surveillance.

Medical laser surveillance is not recommended for personnel using Class 1, 1M, 2, 2M or 3R laser systems as defined in Section 1.2.

Medical laser surveillance is required personnel using or working near Class 3B and 4 lasers systems. Further information is provided in Appendix E.

6.2.1 Personnel Categories. Employee's category is determined by the LSO. Individuals who should be under laser medical surveillance are defined in Sections 6.2.2 and 6.2.3.

6.2.2 Incidental Personnel. Incidental personnel are those whose work makes it possible (**but unlikely**) that they will be exposed to laser energy sufficient to damage their eyes or skin, (e.g., custodial, clerical, and supervisory personnel not working directly with laser devices).

6.2.3 Laser Personnel. Laser personnel are those who work routinely in laser environments. These personnel are ordinarily fully protected by engineering controls/administrative controls.

6.3 General Procedures.

6.3.1 Incidental personnel should have an eye examination for visual acuity (see Appendix E).

6.3.2 Laser personnel shall be subject to the following baseline eye examination:

Ocular history (Appendix E3.2.1). If ocular history shows no problems and visual acuity (Appendix E3.2.2) is found to be 20/20 (6/6 in each eye for far & near) with corrections (worn or not), and Amsler Grid Test (Appendix E3.2.3) and Color Vision (Appendix E3.2.4) responses are normal, no further examination is required. Laser workers with medical conditions noted in Appendix E3.2.1 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 fundoscopic examination (Appendix E3.2.5), or other tests as determined appropriate by the responsible medical or optometric examiner.

6.4 Frequency of Medical Examinations.

For incidental and laser personnel, exam should be performed prior to laser work. Following any suspected laser injury, the pertinent required exams shall be repeated, in addition to any other exams may be desired by the attending physician. Periodic exams are not required.

7. Non-Beam Hazards

7.1 General.

It is important to address hazards associated with the use of lasers not related to exposure of the eye and skin to the laser beam. Non-beam hazards are a class of hazards that do not result from direct human exposure to a laser beam.

These hazards include physical, chemical, and biological agents. And may occur when: a material is exposed to a laser beam (fire or airborne contaminants); materials used to generate the beam (flow-through gases, dyes and solvents) are released into the atmosphere; or when individuals contact system components (shock, electrocution). Some can be life threatening (electrocution). So, the hazards discussed here require use of control measures different from those discussed in Section 4. Also, all written SOPs shall address non-beam hazards as well as beam hazards. Because of the diversity of non-beam hazards, the LSO may employ safety / industrial hygiene personnel to effect evaluations. Appendix F gives more background material / references on non-beam hazards to assist in recognizing potential hazards.

7.2 Physical Agents.

7.2.1 Electrical Hazards. Electrical equipment in general presents three potential hazards: shock, resistive heating, and ignition of flammable materials.

7.2.1.1 Shock. Laser systems present an electric shock hazard which may occur from contact with electrical conductors contained in control systems, power supplies, and devices that operate at potentials of ≥ 50 volts. Exposures can occur during laser installation, maintenance, modification, or service, when protective covers are removed to allow access to components. The exposed can be installers, users, techs, and members of the public. The effect can range from a minor “tingle,” to startle reaction, to serious personal injury, or death. Current pathways depend on complex parameters, so shock occurrence / outcome are difficult to predict. Electric shock is a serious opportunistic hazard. Death has occurred during electrical servicing / testing of lasers with high-voltage power supplies. Protection against contact with energized conductors using a barrier system is the primary method to prevent laser electric accidents. Warnings/instructions extend the system to embody exposures caused by conditions of use, maintenance, and service, and provide protection against hazards of equipment misuse. It is recommended that surge protection be provided to minimize transients, spikes, harmonics, outage, and electromagnetic interference (EMI).

7.2.1.2 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, it is important that this equipment be regularly checked for excessive resistive heating symptoms such as component warping, discoloration, or corrosion, and repaired as needed.

7.2.1.3 Electric Spark Ignition of Flammable Materials. Equipment malfunctions can lead to electrical fires. Electrical sparks can serve as an ignition source.

7.2.1.4 Electrical Hazard Control Measures. Additional electrical safety requirements are imposed upon laser devices, systems, and those who work with them, by the United States Department of Labor, Occupational Safety and Health Administration (OSHA), the National Electrical Code (NFPA 70), 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. Requirements must be observed with all laser installations. And, it is recommended that fire extinguishers designed for electrical fires be used with laser systems. A “Panic Button” as described in Section 4 can also eliminate or minimize electrical hazards in an emergency. The following potential electrical problems have frequently been identified during laser facility audits:

- (1) Uncovered and improperly insulated electrical terminals
- (2) Hidden “power-up” warning lights
- (3) Lack of personnel trained in CPR practices, or lack of refresher training (Section 5.2)
- (4) “Buddy system” /equivalent measure not used during maintenance and service
- (5) Failure to properly discharge and ground capacitors
- (6) Non earth-grounded or improperly grounded laser equipment
- (7) Non-adherence to the OSHA lock-out standard (29 CFR 1910.147)
- (8) Excessive wires and cables on floor that create fall or slip hazards

7.2.2 Collateral and Plasma Radiation. Collateral radiation is radiation other than that associated with the primary beam and is produced by components such as power supplies, discharge lamps and plasma tubes. This may take the form of x-radiation, UV, visible, IR, microwave and radio-frequency (RF) radiation.

Plasma radiation is generated when energetic laser beam interacts with matter, usually metals. Occurs when high power pulsed lasers (irradiance $\sim 10^{12}$ Wcm⁻²) are focused on a target.

7.2.2.1 Collateral Radiation.

7.2.2.1.1 Radiation. X-radiation may be generated by electronic components of the laser, e.g., high-voltage vacuum tubes (usually greater than 15 kV) and from laser-metal induced plasmas. All generated radiation (intentional or not) should be controlled in accordance with the provisions listed in applicable federal, state, or local codes and regulations.

7.2.2.1.2 Ultraviolet (UV) and Visible Radiation. Collateral UV emitted from laser discharge tubes and pump lamps shall be suitably shielded so that personnel exposures are maintained within exposure limits specified by the ACGIH. UV radiation may cause photodermatitis/photokeratitis. Photosensitizing agents from industrial chemicals or medications can make one more susceptible to those effects. See Appendix E for a list of such agents. UV radiation at short wavelengths may produce ozone that will need to be exhausted.

7.2.2.1.3 Electric, Magnetic and Electromagnetic Fields. Power supplies and other electrical equipment associated with some lasers are capable of generating intense power frequency electric and magnetic fields (50 or 60 Hz and harmonics).

7.2.2.2 Plasma Radiation. Plasma emissions created during laser-material interaction processes may contain sufficient UV and blue light (0.18 to 0.55 m) to raise concern about long-term ocular viewing without protection. Studies have shown that the integrated blue-light irradiance levels are much higher for CO₂ than for Nd:YAG lasers.

7.2.3 Fire Hazards. Class 4 laser beams represent a fire hazard. Enclosure of Class 4 laser beams can result in potential fire hazards if enclosure materials are likely to be exposed to irradiances exceeding 10 W cm⁻² or beam powers exceeding 0.5 W.

(The National Fire Protection Agency (NFPA) states that for CW lasers 0.5 W cm⁻² is a possible ignition hazard.)

Use of flame retardant materials is encouraged wherever applicable in laser applications. Opaque barriers, curtains, can be used to block the beam from exiting the work area during certain operations (Section 4.6). While 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 (production of smoke, open fire, or penetration). Class 4 laser users should be aware that unprotected wire insulation and plastic tubing can catch on fire from intense reflected/scattered beams, particularly from lasers operating at invisible wavelengths.

7.2.4 Explosion Hazards. High-pressure arc lamps, filament lamps, and capacitor banks in laser equipment shall be enclosed in housings which can withstand the maximum explosive pressure resulting from component disintegration. The laser target and elements of the optical train which may shatter during laser operation shall also be enclosed or equivalently protected to prevent injury to operators and observers. Explosive reactions of chemical laser reactants or other laser gases may be a concern in some cases.

Explosions may be caused by the ignition of dust that has collected in ventilation systems serving laser processes. This potential can be greatly minimized by good maintenance practice.

7.2.5 Noise. Noise levels from certain lasers, such as pulsed excimers, and their work environment, may be of such intensity that noise control may be necessary.

7.3 Chemical Agents.

Include laser generated airborne contaminants, compressed gas, dyes/solvents, & assist gases.

7.3.1 Laser generated Air Contaminants (LGAC). Air contaminants may be generated when certain Class 3B and 4 laser beams interact with matter. The quantity, composition, and chemical complexity of the LGAC depend greatly upon target material, cover gas, and the beam irradiance. The LSO shall ensure that industrial hygiene aspects of exposure to LGAC are addressed and that appropriate control measures are affected. While it is difficult to predict what LGAC may be released a given interaction situation, contaminants, including a many new compounds, can be produced with many lasers. When the target irradiance reaches a given threshold, approximately 10⁷ W cm⁻² (Table F 1(a) Appendix F), target materials including plastics, composites, metals, and tissues may liberate carcinogenic, toxic and noxious airborne contaminants. Amounts of the LGAC may be greater for lasers that have most of their energy absorbed at the material surface. Compounds may be gaseous or particulate and can, under certain conditions, pose occupational concern (Appendix F).

Special optical materials used for far infrared windows / lenses have been the source of potentially hazardous levels of airborne contaminants. For example, calcium telluride and

zinc telluride will burn in the presence of oxygen when beam irradiance limits are exceeded. Exposure to cadmium oxide, tellurium, and tellurium hexafluoride should also be controlled. The LSO shall ensure that appropriate industrial hygiene characterizations of exposure to LGAC are effected in accordance with applicable federal, state, and local requirements. After characterizing the contaminant, it may be necessary to affect appropriate controls

7.3.2 Compressed Gases. Many hazardous gases are used in lasers and laser applications including chlorine, fluorine, hydrogen chloride, and hydrogen fluoride. All compressed gases having a hazardous material information system (HMIS) health, flammability, or reactivity rating of 3 or 4 shall be contained in an approved / appropriately exhausted gas cabinet that is alarmed with sensors to indicate potential leakage. SOP's shall be developed for safely handling compressed gases. Safety problems occurring with these gases are:

- (1) Working with a free-standing cylinder not isolated from personnel
- (2) Failure to protect open cylinders from atmosphere and contaminants
- (3) No remote shutoff valve or provisions for purging gas before disconnect or reconnect
- (4) Labeled hazardous gas cylinders not maintained in appropriate exhausted enclosures
- (5) Gases of different categories (toxic, corrosive, flammable, oxidizer, inert, and cryogenic) not stored separately, required by OSHA /Compressed Gas Association.

7.3.3 Laser Dyes and Solvents. Are complex fluorescent organic compounds which, with certain solvents, form lasing mediums for dye lasers. Some are highly toxic/carcinogenic. Since these dyes often need to be changed, care must be taken when handling them to prepare solutions from them, and operating dye lasers. An MSDS for dye compounds shall be available to all appropriate workers. The use of dimethylsulfoxide (DMSO) as a solvent for cyanine dyes in dye lasers should be discontinued. DMSO aids in the transport of dyes through the skin and into the blood stream. If another solvent cannot be found, low permeability gloves should be worn by personnel any time a situation arises where contact with DMSO may occur. Dye lasers containing at least 100 mL of flammable liquids shall conform with the provisions of NFPA (NFPA 30 / 45), and NEC (Article 500 - Hazardous Locations). Laser dyes shall be prepared in a laboratory fume hood. Dye pumps/reservoirs should be in secondary containment vessels to minimize leakage /spills.

7.3.4 Assist Gases. These gases may be used to: produce an inert atmosphere, remove material from the beam-interaction site, and minimize deposition on components (mirrors or lenses). They have appeared in LGAC and the spectral distribution of plasma radiation.

7.3.5 Control Measures. In general there are three major control measures available to reduce the concentration of chemical agents to acceptable levels. They are exhaust ventilation, respiratory protection, and isolation of the process. The priority of control requires that engineering controls be used as the primary control measure, with respiratory protection (and other forms of PPE) used as supplementary controls.

7.3.5.1 Exhaust Ventilation. Recirculation of LGAC should be avoided. Exhaust ventilation shall be used to ensure that all personnel exposures to hazardous concentrations of LGAC are maintained at or below the allowable levels specified by OSHA, NIOSH, ACGIH, or other applicable authorities. When possible, enclosing hoods should be used to control LGAC. These hoods afford better control with lower air volumes than exterior hoods, are less susceptible to drafts, and may provide protection from reflected and scattered radiation.

7.3.5.2 Respiratory Protection. This may be used to control brief exposures, or as an interim control measure until other engineering/administrative controls are implemented.

7.3.6 Process Isolation. The laser process may be isolated by physical barriers, master-slave manipulators, or remote control apparatus. Also, during biomedical applications the work area and personal protective equipment shall be disinfected or sterilized immediately after use.

7.3.7 Sensors and Alarms. Sensors shall be installed in hazardous gas cabinets and other locations as appropriate. Exhaust ductwork should be of rigid construction, especially for hazardous gases. Sensors/associated alarm systems should be used for toxic/corrosive agents

such as halogen gases. Sensors should always be able to detect the hazardous gas in a mixture of emitted gases, (fluorine versus hydrogen fluoride). Detection systems must be properly shielded to minimize susceptibility to electromagnetic interference (EMI).

7.4 Biological Agents.

These include LGAC and infectious materials. LGAC may be generated when high power laser beams interact with tissue. Infectious materials, such as bacteria and viral organisms, may survive beam irradiation and become airborne. (Appendix F.)

7.5 Human Factors.

7.5.1 Ergonomics. The LSO shall be aware of hazards created by neglecting ergonomic principles in laser system designs, such as poor workstation layout, worker-machine interface, manual handling techniques, and area illumination.

Painful arm, hand, and wrist injuries (e.g., carpal tunnel syndrome) may result from repetitive motions occurring during the use of some laser products.

7.5.2 Limited Work Space. There is limited work space or area in many laser system installations. This can present a problem while working near or around mechanical or high voltage equipment (National Electric Code, Section 110-16). There must be sufficient room for personnel to turn around/maneuver freely (OSHA 29 CFR 1910). The issue is compounded when more than one laser is being operated at a time. Whenever laser systems are used in limited work space, local exhaust, mechanical ventilation and respiratory protection shall be used if LGACs are present.

7.5.3 Work Patterns. Swing and third shift work patterns have been shown to affect worker alertness, as well as extended or excessive work hours and hence safety compliance.

7.5.4 Laser and Laser Waste Disposal.

7.5.4.1 Laser Disposal. There are three basic ways to dispose of lasers.

The first method is to give/donate the laser to an organization that can use it. Such organizations might be schools, industrial companies, hospitals, etc. The donor should assure that the equipment being given complies with all applicable product safety standards, such as the FLPPS, and is provided with adequate safety instructions for operations and maintenance. Donor should ensure that the laser will be used by individuals who are trained in laser safety. Another approach may be to return the laser to the manufacturer for credit toward a new laser. The second method is to eliminate the possibility of activating the laser by removing all means by which it can be electrically activated. After this the laser could then be disposed. The third method would be to destroy the laser.

The last two methods could have land fill restrictions due to the possibility of hazardous materials being part of the laser components, i.e., mercury switches, oils, and other chemicals.

7.5.4.2 Laser Waste Disposal. 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.

7.5.5 Chillers. Lasers can produce as much as 2-1000 watts of heat for every watt of optical power generated. To control this heat, 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 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 equipment.

8. Criteria for Exposures of Eye and Skin

For questions concerning the MPE for your respective laser, consult Tables 5a and 5b. For

calculations concerning the MPE, contact the LSO.

Maximum permissible exposures (MPE) are below known hazardous levels. 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 from the laser beam, such as flash-blindness, glare, and startle (which can create secondary hazards) have become an increasing concern. MPEs are expressed (normalized) relative to the limiting aperture area and, therefore, a limiting aperture or cone angle shall be used for measurements or calculations with all MPEs. This is the maximum circular area over which irradiance/radiant exposure can be averaged. Irradiance values for the MPEs in Tables 5a and 5b can be obtained by dividing the radiant exposure by the exposure duration, t , in seconds. Values for the radiant exposure can be obtained by multiplying the irradiance by the exposure duration, t , in seconds. For photochemical effects, the MPEs are provided in Table 5b as radiance or integrated radiance.

8.1 Ocular Exposures From Point Sources and Extended Sources.

For the purpose of this manual, within the retinal hazard region (0.4 to 1.4 m) sources are considered either point or extended.

Point sources subtend a visual angle less than or equal to 1.5 mrad. Point source MPEs are listed in Table 5a.

Extended sources subtend an angle greater than 1.5 mrad. MPEs for extended sources are listed in Table 5b.

Instead of using a computed time, both the thermal and photochemical MPEs in the wavelength range of 0.4 m to 0.6 m must be computed to determine the lower MPE.

Non-uniform sources (laser arrays, multiple diode lasers, or non-uniform diffuse reflections) require special considerations if the source subtends an angle greater than 1.5 mrad.

Each independent subsource of the extended source shall be considered as a separate source and the results compared with the MPE based on the source size of the separate source. Then the entire source (or any combination of subsources) shall be considered as a single source and the MPE shall be based on the size of the combination of subsources. Combinations of sources whose centers are separated by greater than 100 mrad are considered independent.

8.2 MPE for Ocular Exposures.

The single-pulse or single-exposure MPEs for ocular exposures are given in Tables 5a/5b.

8.2.1 Wavelength. The wavelength (λ) must be specified to establish which spectral region is applicable. MPE's in Tables 5a and 5b are arranged in wavelength regions expressed in micrometers (μm). For multiple wavelength laser emissions, MPE must first be determined for each wavelength. Exposures from several wavelengths in the same time are additive on a proportional basis of spectral effectiveness with due allowance for all correction factors. In the UV region, special considerations may apply for multiple exposures.

8.2.2 Exposure Duration. Exposure duration is equal to pulse duration. For non-visible wavelengths ($<0.4 \mu\text{m}$ & $> 0.7 \mu\text{m}$), CW exposure duration is maximum time of anticipated direct exposure. MPEs for single-pulse exposures between 10^{-13} and 10^{-9} seconds, at 0.4 m - 1.4 m are listed in Tables 5a and 5b. For pulse durations < 100 fs in the retinal hazard region ($0.4 \text{ m} < < 1.4 \text{ m}$), it is recommended that peak irradiance be limited to MPEs applicable to 100 fs pulses. For pulse durations less than 1 ns outside of the retinal hazard region ($< 0.4 \text{ m}$ and $> 1.4 \text{ m}$) it is recommended that the peak irradiance be limited to MPEs applicable to 1 ns pulses. For CW or multiple-pulsed visible (0.4 – 0.7 m) laser, exposure duration is maximum time of anticipated exposure. If purposeful staring into the beam is not intended/anticipated, the aversion response time, 0.25 s, may be used.

8.2.3 Repeated Exposures. For repetitive-pulse lasers, no single pulse in the train can exceed the single-pulse MPE. The radiant exposure from a modulated output or from a

group of pulses of duration T shall not exceed the MPE applicable to a single unmodulated exposure of time T . The total exposure duration t_{\max} of the train of pulses is determined in the same manner as for CW laser exposures.

Rule 1: Single-Pulse MPE. The exposure from any single pulse in a train of pulses shall not exceed the MPE for a single pulse of that pulse duration. (Rule 1 protects against thermal injury from any single pulse having greater than average energy.)

Rule 2: Average Power MPE for Thermal and Photochemical Hazards. The exposure from any group of pulses (or sub-group of pulses in a train) delivered in time T shall not exceed the MPE for time T . That is, the total radiant exposure of all pulses within any part of the train shall not exceed the MPE for the duration of that part. The calculation of Rule 2 usually provides a lower MPE for lasers with a high duty cycle than by applying Rule 3 below. (Rule 2 protects against cumulative injury from photochemical damage mechanisms and also against heat buildup from average power for thermal injury.)

Rule 3: Multiple-pulse MPE for Thermal Hazards. The exposure for any single pulse ($t < 0.25$ sec) or group of pulses ($T < 0.25$ sec) shall not exceed the single-pulse MPE. (Rule 3 protects against sub-threshold pulse-cumulative thermal injury.) The methods of applying the three rules for determining the MPEs for repetitive laser exposures for specific spectral bands are given in 8.2.3.1 to 8.2.3.3. See 8.2.3.3 for proper apertures to use with each rule.

8.2.3.1 Repeated Exposures, Ultraviolet (0.180 to 0.400 m) – Special Considerations.

Photochemical effects generally are dominant in this spectral region, but dual limits do exist. The Rules from 8.2.3 are used to find those limits. Rules 1 and 2 apply to both limits, but Rule 3 applies only to the thermal limit (i.e., the MPE expressed as $0.56 t^{0.25}$).

8.2.3.2 Repeated Exposures, Visible (0.4 to 0.7 m) and Infrared (0.7 to 1.4 m). Dual limits apply in the short-wavelength part of the spectral region and the values from 8.2.3 are used for the calculations. For repeated exposures, the MPE per pulse is the lowest of the three calculated results using Rules 1, 2, and 3. In all cases, the maximum duration to apply in determining “ n ” for Rule 3 from the duration of the pulse train T shall be $T/2$ seconds.

8.2.3.3 Repeated Exposures, Infrared (1.4 m to 1 mm). Only thermal effects occur in this spectral region. The lower MPE calculated from Rules 2 and 3 from Section 8.2.3 determines the actual MPE.

8.3 MPE for Skin Exposure to a Laser Beam.

MPEs for skin exposure to a laser beam are given in Table 7. These levels are for worst-case conditions and are based on the best available information.

8.3.1 MPE for Skin, Repeated Exposures. For repetitive-pulse lasers the MPEs for skin exposure are applied as follows: Exposure of the skin shall not exceed the MPE based upon a single pulse exposure, and the average irradiance of the pulse train shall not exceed the MPE applicable for the total pulse train, duration T .

APPENDIX A, TABLES

Table 2. Recommended Limiting Exposure Durations for CW and

Wavelength Rang	Diffuse (seconds)	Intrabeam (seconds)
UV 0.18 to 0.4 μ m	30,000	30,000
Visible 0.4 to 0.7 μ m	600	0.25**
NIR 0.7 to 1.4 μ m	600	10
FIR 1.4 μ m to 1 mm	10	10

Repetitive-Pulse MPE Calculations*

- * For single pulse lasers (PRF < 1 Hz) use actual laser pulse duration.
- ** For unintended or accidental viewing only. For other conditions, use the time of *intended* viewing.

Table 3. Diffusely Reflected Beam Energy in Joules that does not Exceed the MPE

Pulsed Lasers (1 ns to 50 s Pulse Duration: Wavelengths Between 0.400 to 1.400 m). †

Beam Diameter (cm)	Viewing Distance, r _l (cm)		
	20	100	1000
0.1	0.002xCA	0.016xCA	1.6xCA
0.2	0.004 x CA	0.021 x CA	1.6 x CA
0.3	0.006xCA	0.032xCA	1.6xCA
0.4	0.008xCA	0.042xCA	1.6xCA
0.5	0.011 x CA	0.053 x CA	1.6 x CA
0.6	0.013xCA	0.063xCA	1.6xCA
0.7	0.015xCA	0.074xCA	1.6xCA
0.8	0.017xCA	0.084xCA	1.6xCA
0.9	0.020xCA	0.095xCA	1.6xCA
1.0	0.022xCA	0.11 xCA	1.6xCA
1.5	0.034xCA	0.16 xCA	1.6xCA
2.0	0.046 x CA	0.21 x CA	2.1 x CA
2.5	0.074 x CA	0.27 x CA	2.6 x CA
3.0	0.11 xCA	0.32 xCA	3.2xCA
3.5	0.15 xCA	0.38 xCA	3.7xCA
4.0	0.20 x CA	0.44 x CA	4.2 x CA
4.5	0.26 x CA	0.49 x CA	4.7 x CA
5.0	0.33 x CA	0.55 x CA	5.3 x CA
6.0	0.50 x CA	0.68 x CA	6.3 x CA
7.0	0.7 xCA	0.79 xCA	7.4xCA
8.0	0.9 xCA	0.91 xCA	8.4xCA
9.0	1.3 xCA	1.0 xCA	9.5xCA
10.0	1.6 xCA	1.2 xCA	11.0xCA

† The table shows the values for pulsed lasers with 1 ns to 18 s pulse durations for the wavelength region 0.400 to 1.050 m and 1 ns to 50 s for the wavelength region 1.050 to 1.400 m.

Note 1: The diffuse reflection values Q are based on the MPE values in Tables 5a and 5b and are calculated from the general equation which is valid for all exposure durations where the MPE in Tables 5a and 5b is expressed in $J\text{ cm}^{-2}$,

$$Q = \frac{\pi(\text{MPE})(r_l + D_p/2)^2}{\rho_\lambda \theta}$$

including those for 100fs to 1 ns. D is the diameter of the laser beam at the reflection site, θ is the viewing angle, ρ_λ is the spectral reflectance as a function of wavelength (where this is not known, the value 1 is used), and r_l is the viewing distance. In calculating the above values, the following was assumed: $\theta = 90^\circ$; $\rho_\lambda = 1$; and $n = 1$ (that is, these values are for the single-pulse case). The MPE values substituted into the above equation must include the correction factors CA , CC , CE , and CP where appropriate, and for wavelengths between 0.4 and 0.55 m, the MPE is the lower value of the thermal and photochemical MPE computations (see Tables 5 and 6 and Section 8.2.3.2).

Note 2: In the wavelength region 1.050 to 1.400 m, the tabular values above are to be multiplied by the term $2 X Cc$ (see Table 6).

Note 3: For targets of known reflectance, the above values may be divided by the reflectance of the target.

Table 4. Simplified Method for Selecting Laser Eye Protection for Point Source Viewing (Wavelengths Between 0.400 and 1.400 μ m) †

Q-Switched Laser (10^{-9} - 10^{-2} s)		Non-Q-Switched Lasers (0.4×10^{-3} - 10^{-2} s)		Continuous-Wave Lasers Momentary (0.25- 10 s)		Continuous-Wave Lasers Long-Term Staring (< 1 hr)		Attenuation	
Maximum Output Energy (J)	Max Beam Radiant Exposure (Jcm ⁻²)	Max Laser Output Energy (J)	Max Beam Radiant Exposure (J cm ⁻²)	Max Power Output (W)	Max Beam Irradiance (W cm-2)	Max Power Output (W)	Max Beam Irradiance (W cm ⁻²)	Attenuation Factor	OD
10	20	100	200		10^7 * 2×10^4 *	100*	200*	10^8	8
1	2	10	20	10^4 *	2×10^4 *	10*	20*	10^7	7
10^{-1}	2×10^{-1}	1	2	10^3 *	2×10^3 *	1	2	10^6	6
10^{-2}	2×10^{-2}	10^{-1}	2×10^{-1}	100 *	200 *	10^{-1}	2×10^{-1}	10^5	5
10^{-3}	2×10^{-3}	10^{-2}	2×10^{-2}	10	20	10^{-2}	2×10^{-2}	10^4	4
10^{-4}	2×10^{-4}	10^{-3}	2×10^{-3}	1	2	10^{-3}	2×10^{-3}	10^3	3
10^{-5}	2×10^{-5}	10^{-4}	2×10^{-4}	10^{-1}	2×10^{-1}	10^{-4}	2×10^{-4}	10^2	2
10^{-6}	2×10^{-6}	10^{-5}	2×10^{-5}	10^{-2}	2×10^{-2}	10^{-5}	2×10^{-5}	10	1

† Use of this table may result in optical densities (OD) greater than necessary. See Section 4.6.2 for other wavelengths.

* Not recommended as a control procedure at these levels. These levels of power could damage or destroy the attenuating material used in the eye protection. The skin also needs protection at these levels.

Table 5a. Maximum Permissible Exposure (MPE) for Point Source Ocular Exposure to a Laser Beam †

Wavelength (μm)	Exposure Duration, t (s)	MPE		Notes
		($\text{J}\cdot\text{cm}^{-2}$)	($\text{W}\cdot\text{cm}^{-2}$)	
Ultraviolet				
<i>Dual Limits for λ between 0.180 and 0.400 μm</i>				
Thermal				
0.180 to 0.400	10^{-9} to 10	$0.56 t_{0.25}$		In the Dual Limit Wavelength Region (0.180 to 0.400 m), the lower MPE considering photochemical and thermal effects must be chosen.
Photochemical				
0.180 to 0.302	10^{-9} to 3×10^4	3×10^{-3}		See Tables 8a and 8b for limiting aperture and Table 9 for measurement aperture.
0.302 to 0.315	10^{-9} to 3×10^4	$10^{200(-0.295)} \times 10^{-4}$		
0.315 to 0.400	10 to 3×10^4	1.0		
Visible				
0.400 to 0.700	10^{-13} to 10^{-11}	1.5×10^{-8}		In the Wavelength Region (0.400 to 0.500 m), T_1 determines whether the photochemical or thermal MPE is lower.
0.400 to 0.700	10^{-11} to 10^{-9}	$2.7 t_{0.75}$		
0.400 to 0.700	10^{-9} to 18×10^{-6}	5.0×10^{-7}		
0.400 to 0.700	18×10^{-6} to 10	$1.8 t_{0.75} \times 10^{-3}$		
0.500 to 0.700	10 to 3×10^4	1×10^{-3}		
Thermal				
0.450 to 0.500	10 to T_1	1×10^{-3}		For extended sources in the retinal hazard region (0.400 to 1.4 μm), see Table 5b.
Photochemical				
0.400 to 0.450	10 to 100	1×10^{-2}		See Table 6 and Figures 8 and 9 for correction factors C_A , C_B , C_C , C_P , C_E , and times T_1 and T_2 .
0.450 to 0.500	T_1 to 100	$C_B \times 10^{-2}$		
0.400 to 0.500	100 to 3×10^4	$C_B \times 10^{-4}$		
Near Infrared				
0.700 to 1.050	10^{-15} to 10^{-11}	$1.5 C_A \times 10^{-8}$		For repeated (pulsed) exposures, see Section 8.2.3. A correction factor, C_P applies to thermal limits, but not to photochemical limits.
0.700 to 1.050	10^{-11} to 10^{-9}	$2.7 C_A t_{0.75}$		
0.700 to 1.050	10^{-9} to 18×10^{-6}	$5.0 C_A \times 10^{-7}$		
0.700 to 1.050	18×10^{-6} to 10	$1.8 C_A t_{0.75} \times 10^{-3}$		
0.700 to 1.050	10 to 3×10^4	$C_A \times 10^{-3}$		
1.050 to 1.400	10^{-13} to 10^{-11}	$1.5 C_C \times 10^{-7}$		The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$, e.g., 0.180 to 0.302 μm means $0.180 \leq \lambda < 0.302 \mu\text{m}$.
1.050 to 1.400	10^{-11} to 10^{-9}	$27.0 C_C t_{0.75}$		
1.050 to 1.400	10^{-9} to 50×10^{-6}	$5.0 C_C \times 10^{-6}$		
1.050 to 1.400	50×10^{-6} to 10	$9.0 C_C t_{0.75} \times 10^{-3}$		
1.050 to 1.400	10 to 3×10^4	$5.0 C_C \times 10^{-3}$		
Far Infrared				
1.400 to 1.500	10^{-9} to 10^{-3}	0.1		Note: The MPEs must be in the same units.
1.400 to 1.500	10^{-3} to 10	$0.56 t_{0.25}$		
1.400 to 1.500	10 to 3×10^4	0.1		
1.500 to 1.800	10^{-9} to 10	1.0		
1.500 to 1.800	10 to 3×10^4	0.1		
1.800 to 2.600	10^{-9} to 10^{-3}	0.1		
1.800 to 2.600	10^{-3} to 10	$0.56 t_{0.25}$		
1.800 to 2.600	10 to 3×10^4	0.1		
2.600 to 1000	10^{-9} to 10^{-7}	1×10^{-2}		
2.600 to 1000	10^{-7} to 10	$0.56 t_{0.25}$		
2.600 to 1000	10 to 3×10^4	0.1		

**Table 5b. Maximum Permissible Exposure (MPE)
for Extended Source Ocular Exposure[†]**

Wavelength (μm)	Exposure Duration, t (s)	MPE		Notes
		(J cm^{-2}) except as noted	(W cm^{-2}) except as noted	
Visible				
0.400 to 0.700	10^{-13} to 10^{-11}	$1.5 C_E \times 10^{-8}$		(See Tables 8a and 9 for limiting apertures)
0.400 to 0.700	10^{-11} to 10^{-9}	$2.7 C_E t^{0.75}$		
0.400 to 0.700	10^{-9} to 18×10^{-6}	$5.0 C_E \times 10^{-7}$		
0.400 to 0.700	18×10^{-6} to 0.7	$1.8 C_E t^{0.75} \times 10^{-3}$		
<i>Dual Limits for λ between 0.400 and 0.600 μm visible laser exposure for $t > 0.7\text{s}$</i>				
Photochemical				
For $\alpha \leq 11$ mrad, the MPE is expressed as irradiance and radiant exposure*				
0.400 to 0.600	0.7 to 100	$C_B \times 10^{-2}$		(See Tables 8a and 9 for limiting apertures)
0.400 to 0.600	100 to 3×10^4		$C_B \times 10^{-4}$	
For > 11 mrad, the MPE is expressed as radiance and integrated radiance*				
0.400 to 0.600	0.7 to 1×10^4	$100 C_B \text{ J cm}^{-2} \text{ sr}^{-1}$		(See Table 8a for limiting cone angle)
0.400 to 0.600	1×10^4 to 3×10^4		$C_B \times 10^{-2} \text{ W cm}^{-2} \text{ sr}^{-1}$	
<i>and</i>				
Thermal				
0.400 to 0.700	0.7 to T_2	$1.8 C_E t^{0.75} \times 10^{-3}$		
0.400 to 0.700	T_2 to 3×10^4		$1.8 C_E T_2^{-0.25} \times 10^{-3}$	
Near Infrared				
	10^{-13} to 10^{-11}	$1.5 C_A C_E \times 10^{-8}$		(See Tables 8a and 9 for limiting apertures)
	10^{-11} to 10^{-9}	$2.7 C_A C_E t^{0.75}$		
	10^{-9} to 18×10^{-6}	$5.0 C_A C_E \times 10^{-7}$		
0.700 to 1.050	18×10^{-6} to T_2	$1.8 C_A C_E t^{0.75} \times 10^{-3}$		
0.700 to 1.050	T_2 to 3×10^4		$1.8 C_A C_E T_2^{-0.25} \times 10^{-3}$	
1.050 to 1.400	10^{-13} to 10^{-11}	$1.5 C_C C_E \times 10^{-7}$		
1.050 to 1.400	10^{-11} to 10^{-9}	$27.0 C_C C_E t^{0.75}$		
1.050 to 1.400	10^{-9} to 50×10^{-6}	$5.0 C_C C_E \times 10^{-6}$		
1.050 to 1.400	50×10^{-6} to T_2	$9.0 C_C C_E t^{0.75} \times 10^{-3}$		
1.050 to 1.400	T_2 to 3×10^4		$9.0 C_C C_E T_2^{-0.25} \times 10^{-3}$	

[†] See Table 6 and Figures 8, 9 and 13 for correction factors C_A , C_B , C_C , C_E , C_P , and times T_1 and T_2 .

* For sources subtending an angle greater than 11 mrad, the limit may also be expressed as an integrated radiance

$$L_p = 100 C_B \text{ J cm}^{-2} \text{ sr}^{-1} \text{ for } 0.7 \text{ s } t < 10^4 \text{ s and } L_e = C_B \times 10^{-2} \text{ W cm}^{-2} \text{ sr}^{-1} \text{ for } t \geq 10^4 \text{ s as measured through a limiting cone angle. These correspond to values of } \text{J cm}^{-2} \text{ for } 10 \text{ s } t < 100 \text{ s and } \text{W cm}^{-2} \text{ for } 100 \text{ s as measured through a limiting cone angle.}$$

$$= 1.1 \text{ mrad for } 0.7 \text{ s } t < 100 \text{ s,}$$

$$= 1.1 t^{0.5} \text{ mrad for } 100 \text{ s } t < 10^4 \text{ s}$$

$$= 1.10 \text{ mrad for } 10^4 \text{ s } t < 3 \times 10^4 \text{ s}$$

See Figure 3 for and Appendix B7.2 for examples.

Note 1: For repeated (pulsed) exposures, see Section 8.2.3.

Note 2: The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$, e.g., 1.180 to 1.302 m means 1.180 $\leq \lambda < 1.302$ m.

Note 3: Dual Limit Application: In the Dual Limit wavelength region (0.400 to 0.600 m), the exposure limit is the lower value of the determined photochemical and thermal exposure limit.

Note 4: The MPEs must be in the same units.

Table 6. Parameters and Correction Factors

Parameters! Correction Factors	Wavelength (m)	Figure with Graphical Representation
$C_A = 1.0$	0.400 to 0.700	8a
$C_A = 10^{2(-0.700)}$	0.700 to 1.050	8a
$C_A = 5.0$	1.050 to 1.400	8a
$C_B = 1.0$	0.400 to 0.450	8c
$C_B = 10^{20(-0.450)}$	0.450 to 0.600	8c
$C_C = 1.0$	1.050 to 1.150	8b
$C_C = 10^{18(-1.150)}$	1.150 to 1.200	8b
$C_C = 8$	1.200 to 1.400	8b
$C_E = 1.0 \alpha / \alpha_{\min}^*$	0.400 to 1.400	—
$C_E = \alpha / \alpha_{\min} \quad \alpha_{\min} \leq \alpha \leq \alpha_{\max}^*$	0.400 to 1.400	
$C_E = \alpha^2 / (\alpha_{\max} \alpha_{\min}) \quad \alpha > \alpha_{\max}^*$	0.400 to 1.400	
$C_P = n^{-0.25} **$	0.180 to 1000	13
$T_1 = 10 \times 10^{20(\lambda - 0.450)} ***$	0.450 to 0.500	9a
$T_2 = 10 \times 10^{(\alpha - 1.5)98.5} ****$	0.400 to 1.400	9b

* For wavelengths between 0.400 and 1,400 μm : $\alpha_{\min} = 1.5$ mrad, and $\alpha_{\max} = 100$ mrad.

** See 8.2.3 for discussion of C_P and 8.2.3.2 for discussion of pulse repetition frequencies below 55 kHz (0.4 to 1.05 m) and below 20kHz (1.05 to 1.4 μm).

*** $T_1 = 10$ s for $\lambda = 0.450$ m, and $T_1 = 100$ s for $\lambda = 0.500$ m.

**** $T_2 = 10$ s for $\alpha < 1.5$ mrad, and $T_2 = 100$ s for $\alpha > 100$ mrad.

Note 1: Wavelengths must be expressed in micrometers and angles in milliradians for calculations.

Note 2: The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$, e.g., 0.550 to 0.700 m means $0.550 \leq \lambda < 0.700 \mu\text{m}$.

**Table 7. Maximum Permissible Exposure (MPE)
for Skin Exposure to a Laser Beam**

Wavelength (m)	Exposure Duration, t (s)	MPE		Notes
		(J cm ⁻²) except as noted	(W cm ⁻²) except as noted	
Ultraviolet				
<i>Dual Limits for λ between 0.180 to 0.400 m</i>				
Thermal 0.180 to 0.400	10^{-9} to 10	$0.56 t^{0.25}$	10^{-4}	In the Dual Limit Wavelength Region (0.180 to 0.400 m), the lower MPE considering photochemical and thermal effects must be chosen. 3.5 mm limiting aperture applies for all wavelengths and exposure durations (see Table 8a).
Photochemical				
0.180 to 0.302	10^{-9} to 3×10^4	3×10^{-3}		
0.302 to 0.315	10^{-9} to 3×10^4	$10^{200(-0.295)}$		
0.315 to 0.400	10 to 10^3	1.0		
0.315 to 0.400	10^3 to 3×10^4		1×10^{-3}	
Visible and Near Infrared				
0.400 to 1.400		10^{-9} to 10^{-7}	$2 C_A \times 10^{-2}$	The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$, e.g., 0.180 to 0.302 μm means $0.180 \leq \lambda < 0.302 \mu\text{m}$.
0.400 to 1.400		10^{-7} to $10^{1.1 C_A t^{0.25}}$		
0.400 to 1.400			10 to 3×10^4	
0.2 C_A				
Far Infrared				
1.400 to 1.500		10^{-9} to 10^{-3}	0.1	The exposure duration t_1 to t_2 means $t_1 < t_2$, e.g., 10 to 10^3 s means $10 \text{ s} < t \leq 10^3 \text{ s}$.
1.400 to 1.500		10^{-3} to 10	$0.56 t^{0.25}$	
1.400 to 1.500			10 to 3×10^4	
1.500 to 1.800	10^{-9} to 10	1.0		See Section 8.4.2 for large beam cross sections and Table 6 for correction factor C_A
1.500 to 1.800	10 to 3×10^4		0.1	
1.800 to 2.600	10^{-9} to 10^{-3}	0.1		
1.800 to 2.600	10^{-3} to 10	$0.56 t^{0.25}$		
1.800 to 2.600	10 to 3×10^4		0.1	
2.600 to 1000	10^{-9} to 10^{-7}	1×10^{-2}		
2.600 to 1000	10^{-7} to 10	$0.56 t^{0.25}$		
2.600 to 1000	10 to 3×10^4		0.1	

Table 10. Control Measures for the Seven Laser Classes

Engineering Control Measures	Classification						
	1	1M	2	2M	3R	3B	4
Protective Housing (4.3.1)	X	X	X	X	X	X	X
Without Protective Housing (4.3.1.1)	LSO shall establish Alternative Controls						
Interlocks on Removable Protective Housings (4.3.2)						X	X
Service Access Panel (4.3.3)						X	X
Key Control (4.3.4)	—	—	—		—	•	X
Viewing Windows, Display Screens and Collecting Optics(4.3.5. 1)	Assure viewing limited < MPE						
Collecting Optics (4.3.5.2)							
Fully Open Beam Path (4.3.6.1)	—	—	—		—	X NHZ	X NHZ
Limited Open Beam Path (4.3.6.2)	—	—	—		—	X NHZ	X NHZ
Enclosed Beam Path (4.3.6.3)	None is required if 4.3.1 and 4.3.2 fulfilled						
Remote Interlock Connector (4.3.7)	—	—	—	—	—	•	X
Beam Stop or Attenuator (4.3.8)	—	—	—		—	•	X
Activation Warning Systems (4.3.9.4)	—	—	—	—	—	•	X
Indoor Laser Controlled Area (4.3.10)	—	*	—	*	—	X NHZ	X NHZ
Class 3B Indoor Laser Controlled Area (4.3.10. 1)	—	—	—		—	X	—
Class 4 Laser Controlled Area (4.3.10.2)	—	—	—	—	—	—	X
Outdoor Control Measures (4.3.11)	X	* NHZ	X NHZ	* NHZ	X NHZ	X NHZ	X NHZ
Laser in Navigable Airspace (4.3.11.2)	X	* NHZ	X NHZ	* NHZ	X NHZ	X NHZ	X NHZ
Temporary Laser Controlled Area (4.3.12)	MPE	MPE	MPE	MPE	MPE	—	—
Controlled Operation (4.3.13)	—	—	—	—	—	—	•
Equipment Labels (4.3.14 and 4.7)	X	X	X	X	X	X	X
Laser Area Warning Signs and Activation Warnings (4.3.9)	—	—	—	—	•	X NHZ	X NHZ

- LEGEND: X Shall
□ Should
— No requirement
- ▽ Shall if enclosed Class 3B or Class 4
MPE Shall if MPE is exceeded
NHZ Nominal Hazard Zone analysis required
* May apply with use of optical aids

Table 10. Control Measures for the Seven Laser Classes (cont.)

Administrative and Procedural Control Measures	Classification						
	1	1M	2	2M	3R	3B	4
Standard Operating Procedures (4.4.1)	— ----	—	—		—	•	X
Output Emission Limitations (4.4.2)	—	—	—	—	LSO Determination		
Education and Training (4.4.3)	—	•	•	•	•	X	X
Authorized Personnel (4.4.4)	—		—	*	—	X	X
Alignment Procedures (4.4.5)						X	X
Protective Equipment (4.6)	—		—	*	—	•	X
Spectators (4.4.6)	—	*	—	*	—	•	X
Service Personnel (4.4.7)						X	X
Demonstration with General Public (4.5.1)	—	*	X	*	X	X	X
Laser Optical Fiber Transmission Systems (4.5.2)	MPE	MPE	MPE	MPE	MPE	X	X
Laser Robotic Installations (4.5.3)	— ----	—	—	—	—	X NHZ	X NHZ
Protective Eyewear (4.6.2)	— ----	—	—		—	•	X
Window Protection (4.6.3)	— ----	—	—	—	—	X	X NHZ
Protective Barriers and Curtains (4.6.4)	—	—	—	—	—	•	•
Skin Protection (4.6.6)	— ----	—	—		— —	X	X NHZ
Other Protective Equipment (4.6.7)	Use may be required						
Warning Signs and Labels (4.7) (Design Requirements)	—	—	•	•	•	X NHZ	X NHZ
Service Personnel (4.4.7)	LSO Determination						
Laser System Modifications (4.1.2)	LSO Determination						

LEGEND: X Shall
 ∩ Should
 — No requirement

 ∇ Shall if enclosed Class 3B or Class 4
 MPE Shall if MPE is exceeded
 NHZ Nominal Hazard Zone analysis required
 * May apply with use of optical aid

APPENDIX B
FIGURES

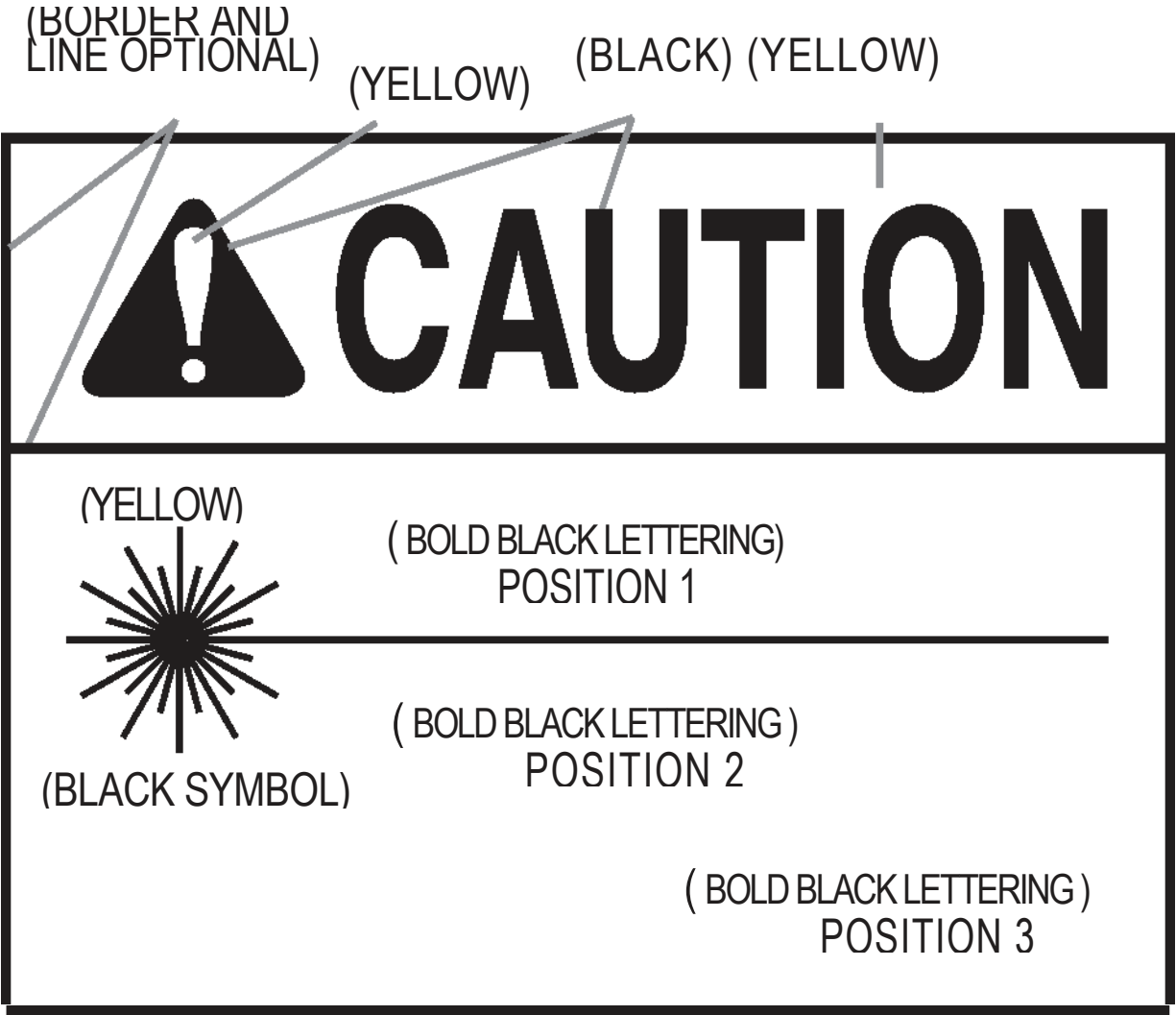


Figure 1a. Sample Warning Sign for Class 2 and Class 2M Lasers

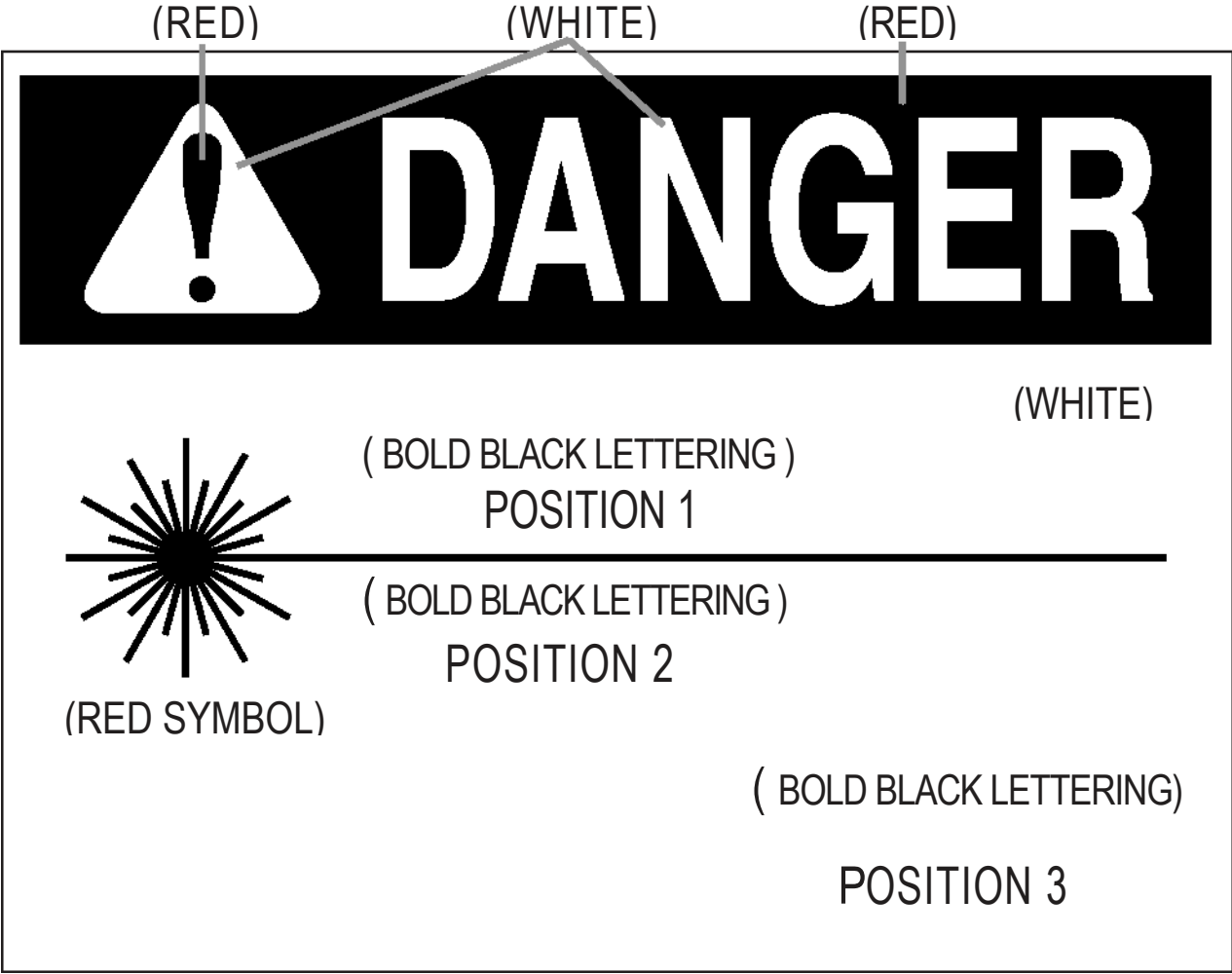
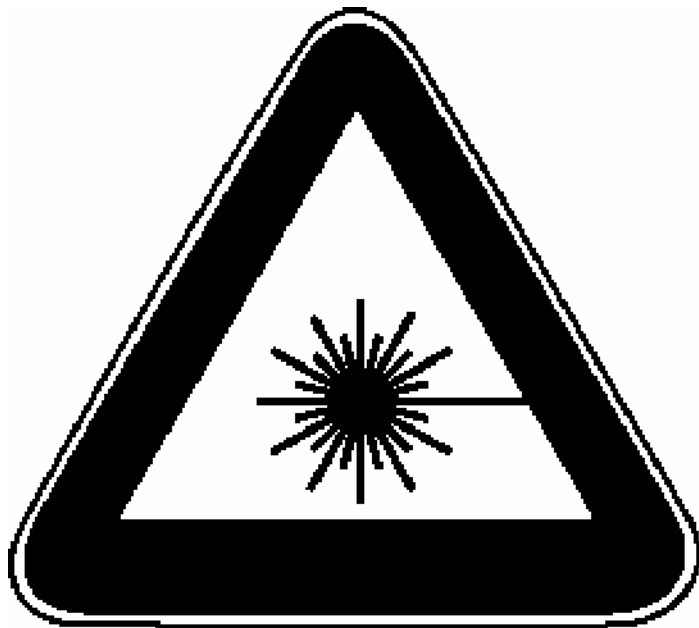
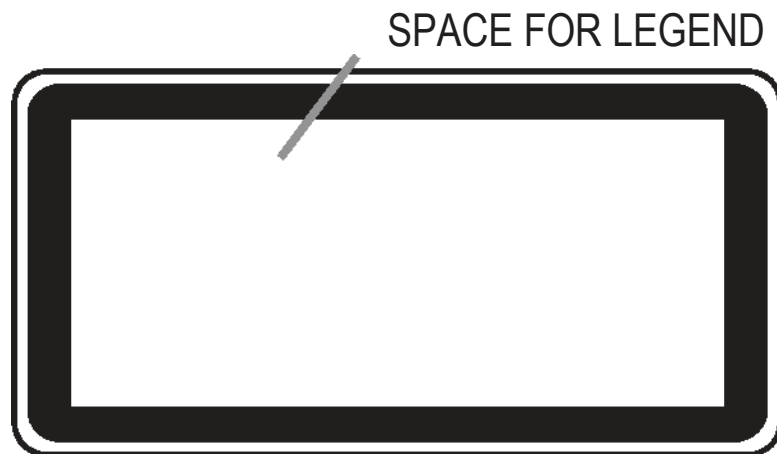


Figure 1b. Sample Warning Sign for Class 3R, Class 3B, and Class 4 Lasers



SYMBOL AND BORDER: BLACK
BACKGROUND: YELLOW



LEGEND AND BORDER: BLACK
BACKGROUND: YELLOW

Figure 1c. IEC Warning Logo and Information Label

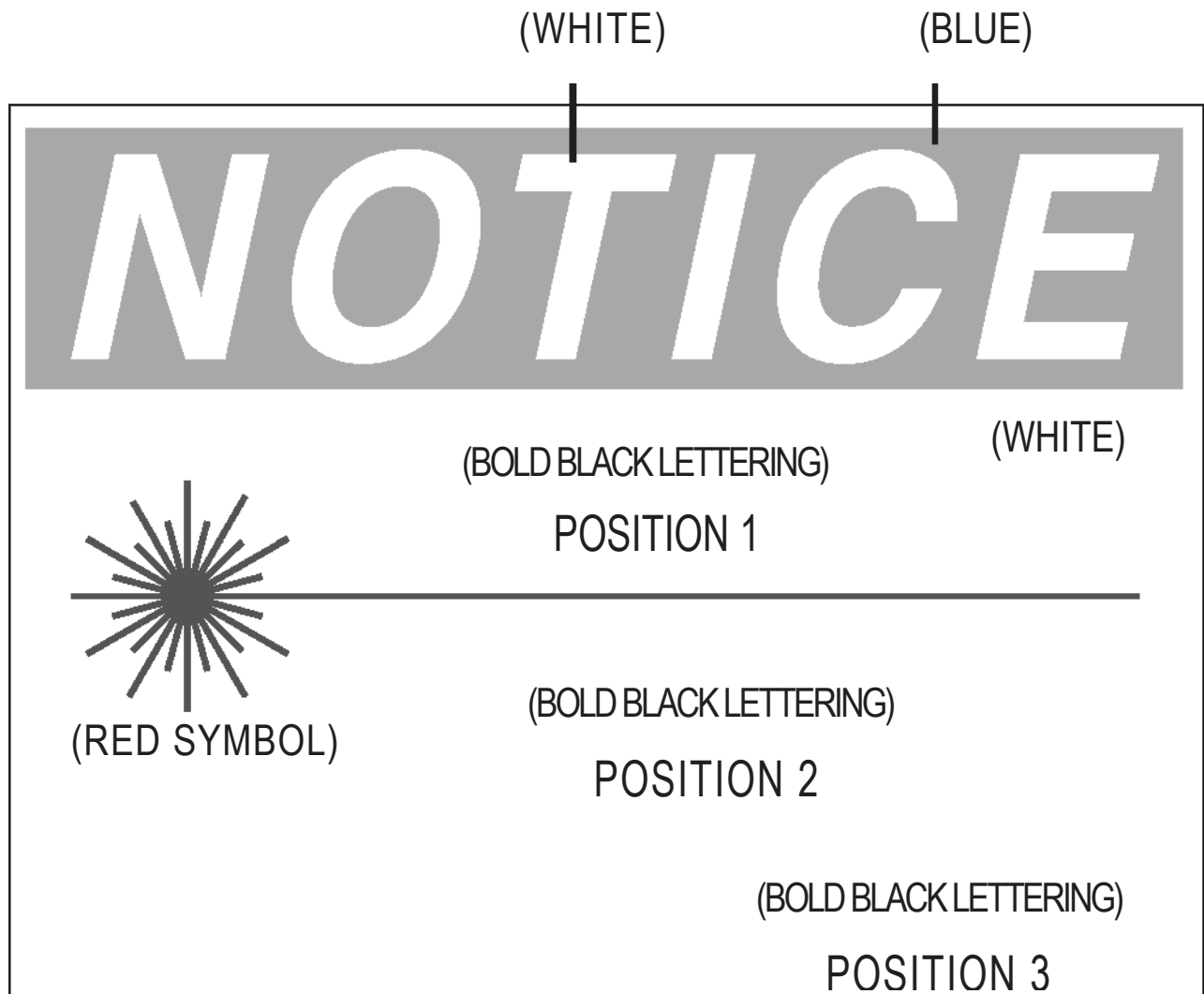
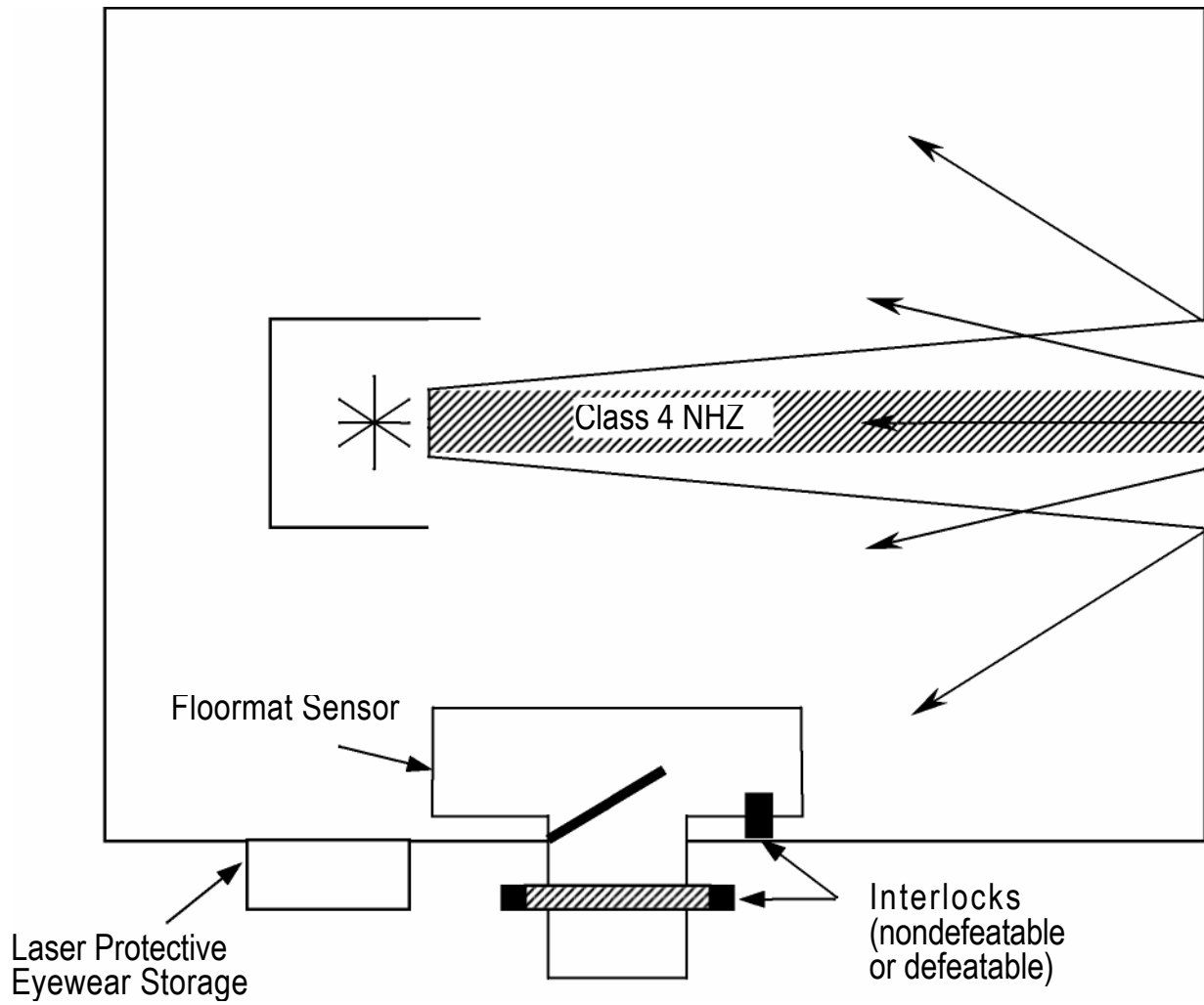


Figure 1d. Sample Warning Sign for Facility Policy, for example, Outside a Temporary Laser Controlled Area During Periods of Service



**Figure 2a. Area/Entryway Safety Controls
for Class 4 Lasers Utilizing Entryway Interlocks**

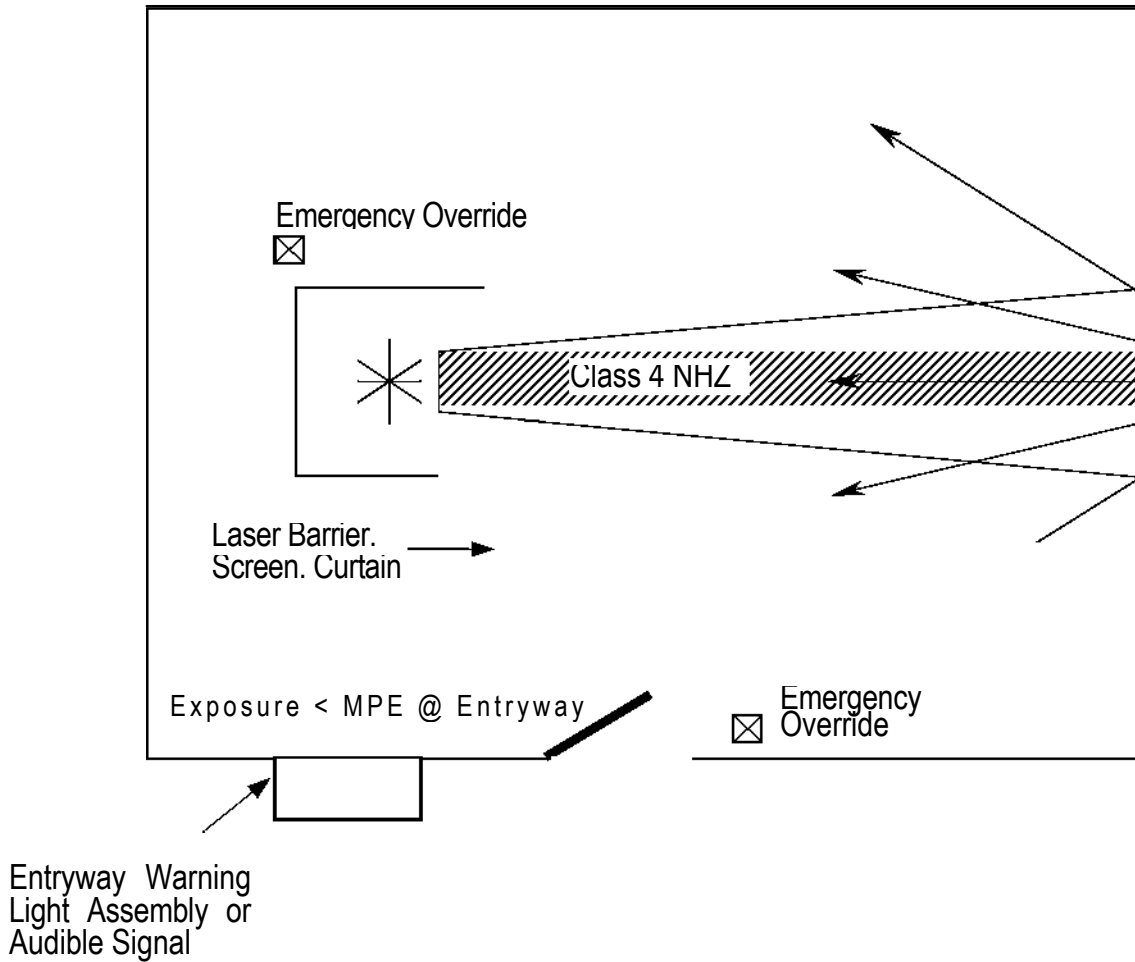


Figure 2b. Entryway Safety Controls for Class 4 Lasers without Entryway Interlock

48See Table 5b.

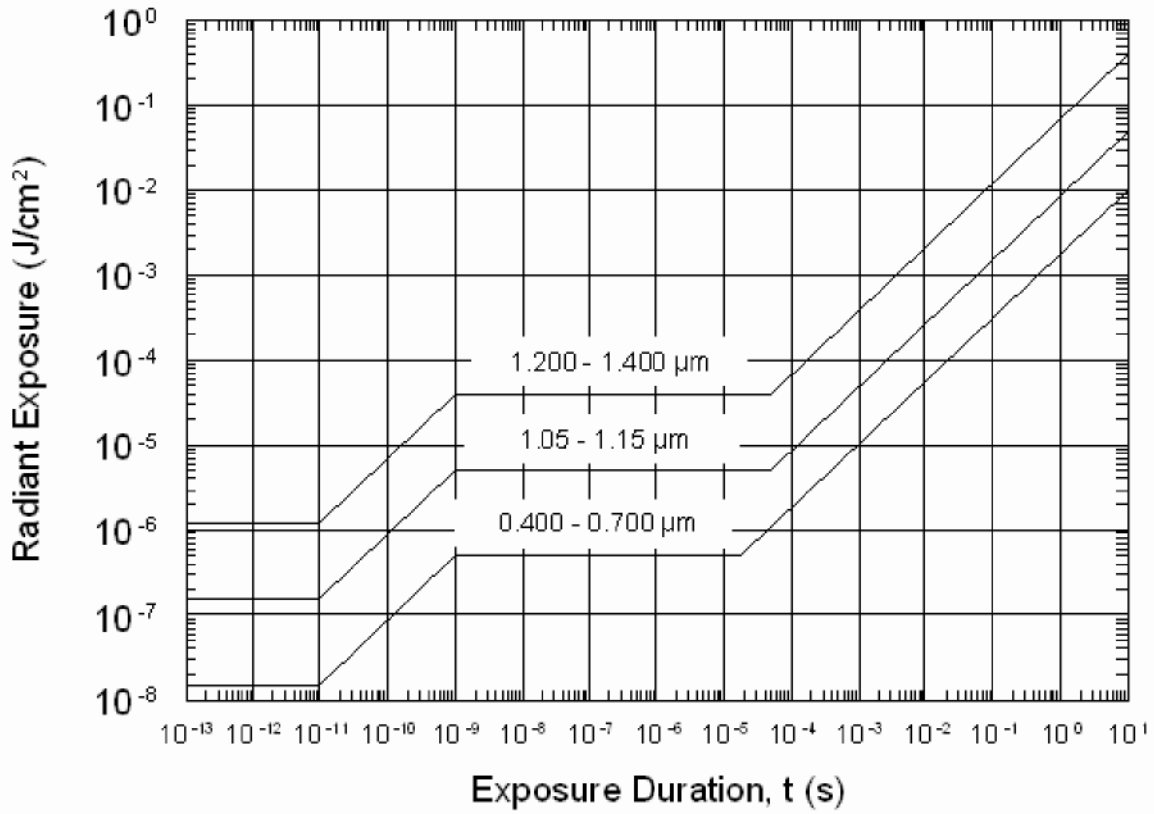


Figure 4. Point Source MPEs for Visible and Near Infrared Pulsed Sources (Wavelengths from 0.400 to 1.400 m)

See Table 5a.

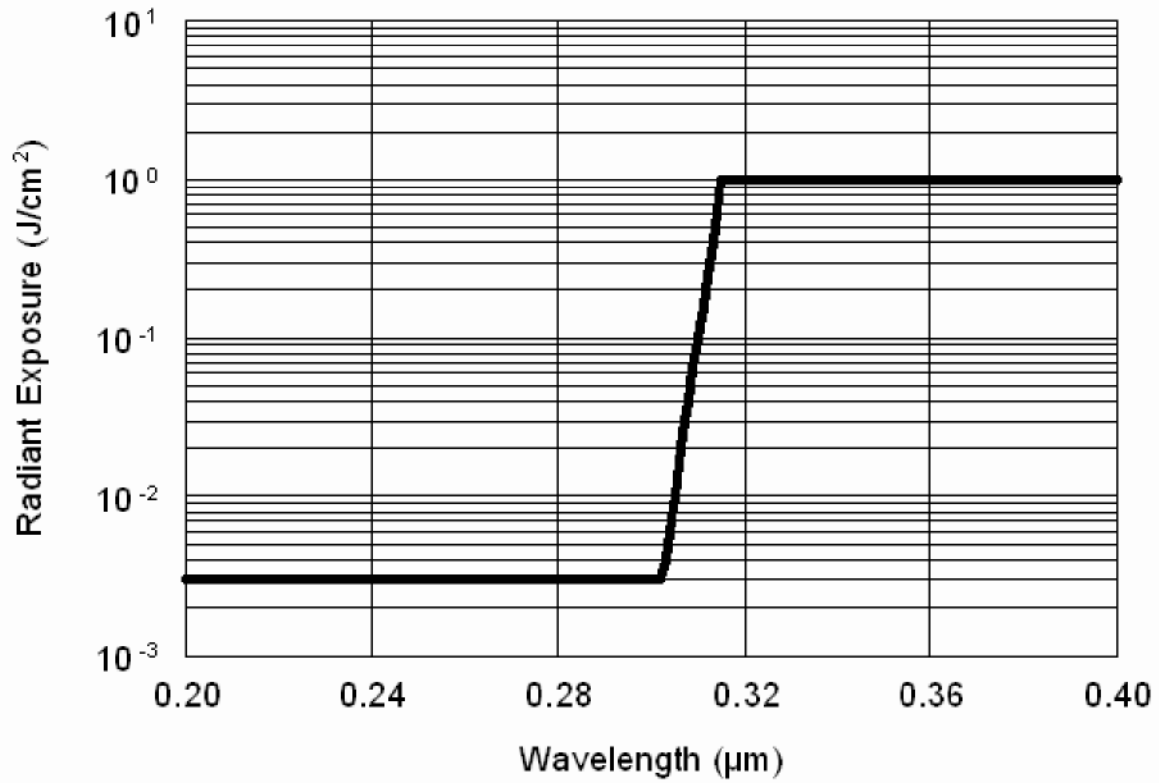


Figure 5. MPE for Ultraviolet Radiation (Small and Extended Sources) for Exposure Duration from 10^{-9} to $3 \cdot 10^4$ s for Ocular Exposure and 10^{-9} to 10^3 s for Skin Exposure*

* Unless $0.56^{0.25}$ is exceeded (possible for exposure durations < 10 s at wavelengths from 0.305 to 0.315 μ).

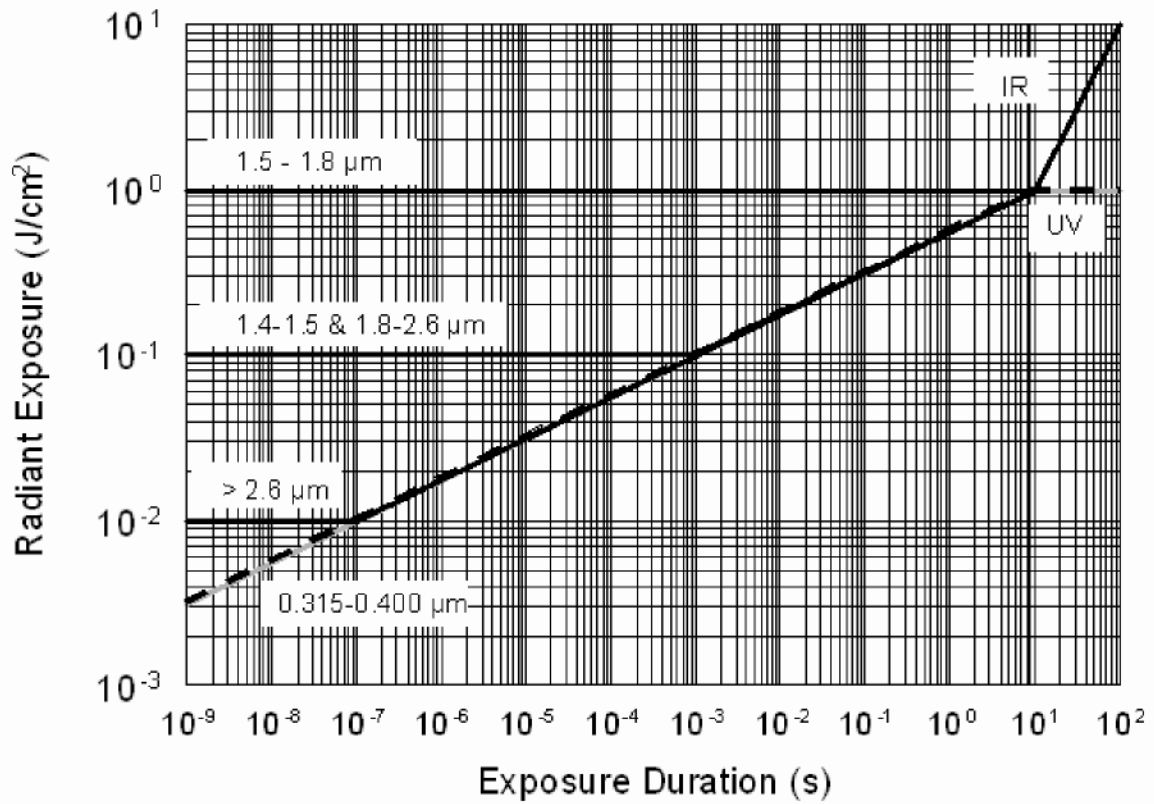


Figure 6. MPE for Ultraviolet (Wavelengths from 0.315 to 0.400 m) and Infrared Radiation (Wavelengths from 1.400 m to 1mm) for Single Pulses or Continuous Exposure (Small or Extended Sources)

See Figure 5 for Wavelengths less than 0.315 m.

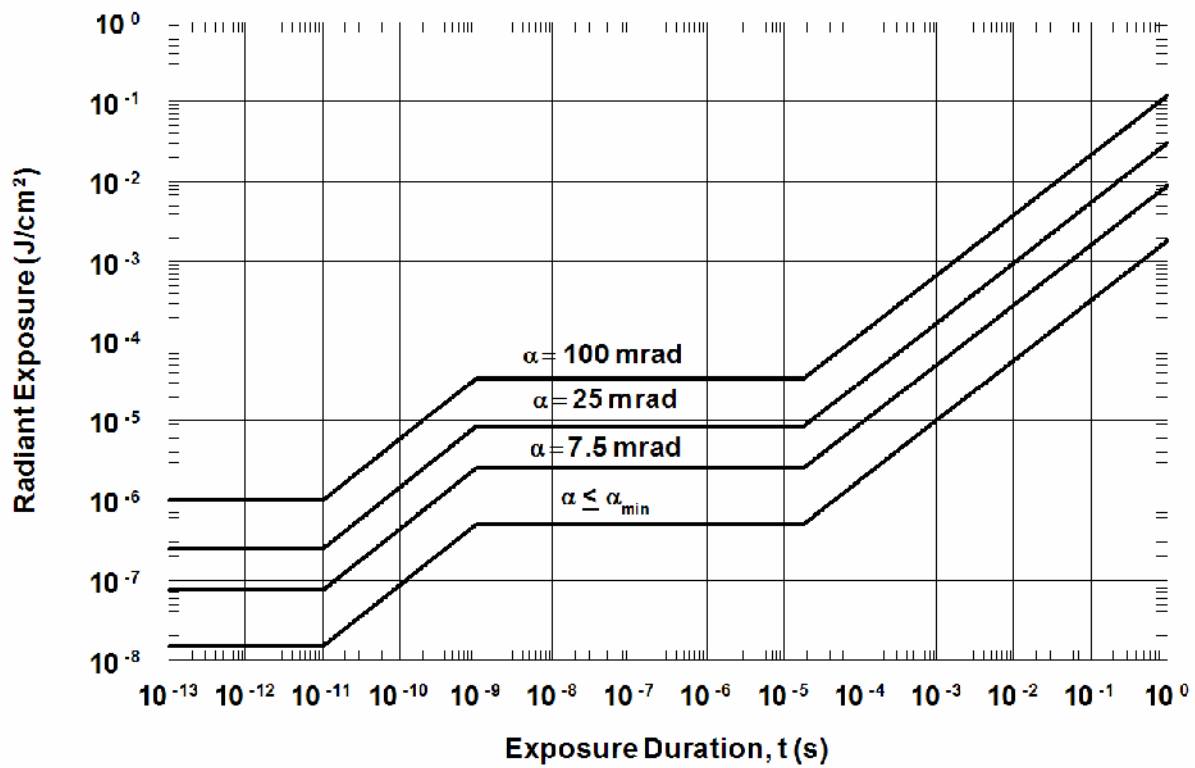


Figure 7. MPE for Ocular Exposure to Visible Laser Radiation (Wavelengths from 0.400 to 0.700 m) for Single Pulses or Continuous Exposure (Small or Extended Sources)

See Tables 5a and 5b.

Appendix C

Hazard Evaluation, Classification and Control Measures

C1. Alternate Labeling

Some laser equipment manufactured outside of the USA may conform to requirements of the IEC Publication 60825, Radiation Safety of Laser Products, Equipment Classification, Requirements and User's Guide (or latest revision thereof). The IEC 60825 label style (shown in Figure 1c) is different from that required by this manual and those specified in the Federal Laser Product Performance Standard.

C2. Laser Protection Damage Threshold Evaluation

C2.1 Laser Protective Eyewear. A variety of commercially available optical absorbing filter materials (glass and plastics) and various coated reflecting "filters" (dielectric and holographic) are available for laser eye protection. Some are available with spectacle lenses ground to prescription specifications. Protection for multiple laser wavelengths is becoming more common as more applications involve several simultaneous wavelengths.

Each filter material has limitations. It should be noted that not all absorbing glass filters used for laser protection are easily annealed (thermally hardened) and, consequently, do not provide adequate impact resistance. In some goggles, however, impact resistant plastic filters (polycarbonate) can be used together with non-hardened glass filters in a design where the plastic is placed in front and behind of the non-hardened laser filter glass.

Some glass filter plates have cracked and shattered following intense Q-switched, pulsed laser exposures. In some instances, the shattering occurred after one-quarter to one-half hour had elapsed following the exposure. And, several glass filter types have displayed photobleaching when exposed to Q-switched laser pulses.

An advantage of using reflective coatings is they can be designed to selectively reflect given wavelength while transmitting as much of the remaining visible spectrum as possible. Some angular dependence of the spectral attenuation factor may be present in dielectric coatings.

The advantages of using absorbing plastic filter materials are greater impact resistance, lighter weight, and convenience of molding the eye protection into comfortable shapes. The disadvantages are that, unless specially coated, they are more readily scratched and the filters often age poorly as the organic dyes used as absorbers are more readily affected by heat and/or ultraviolet radiation, which eventually causes the filter to significantly darken.

It should be stressed that there are few known materials that can withstand laser exposures which exceed 105 W cm^{-2} since the electric fields associated with the beam will exceed the bonding forces of matter. However, most materials will begin to degrade at levels far below these field strength levels due to thermal or shock effects.

C2.2 Laser Eyewear Filter Damage Level. At a specific beam intensity, the filter material absorbing the laser radiation can be damaged. Plastic materials have much lower thresholds than glass filters and glass is lower than glass coated with reflective dielectric coating. The damage threshold is especially important for workers close to the beam interaction site where there is a much higher probability of receiving a direct exposure. Typical damage thresholds for CW lasers fall between 500 and 1000 W cm^{-2} for dielectric coated glass, 100 to 500 W cm^{-2} for uncoated glass and 1 to 100 W cm^{-2} for plastics.

Analysis of polycarbonate protectors with CO_2 lasers indicated that a level of 60 W cm^{-2} for 10 s was just below the penetration level. A level of 112 W cm^{-2} for 4 s just produced penetration and 10 seconds produced significant penetration. While direct intrabeam exposure of eyewear is certainly not recommended under normal condition, it can occur.

C2.3 Protective Viewing Windows. Viewing portals, optics, windows or display screens included as a part of the laser installation shall incorporate some means to attenuate the laser radiation transmitted through the windows to levels below the appropriate MPE. This would include, for example, a viewing window into the laser facility. The filtration requirements would be based upon the level of laser radiation that would occur at the window in a typical worst-case condition in a manner identical to the eyewear evaluations discussed above.

C2.4 Laser Barriers and Protective Curtains. Area control can be affected using barriers which have been specifically designed to withstand either direct /or diffusely scattered beams. In this case, it will exhibit a barrier threshold limit for beam penetration barrier during a specified exposure time (~ 60 seconds). The barrier is located at a distance from the laser source so the threshold limit is not exceeded in the worst-case scenario. Currently laser barriers exhibit threshold limits ranging from 10 W cm^{-2} to 350 W cm^{-2} for different laser wavelengths and power levels. A hazard analysis can be performed in a manner similar to the NHZ evaluations that establishes the recommended barrier type and installation separation distances between the barrier and a given laser. The factor of flammability is important in the design of a protective barrier. It is essential that the material not support combustion or be consumed by flames following the termination of the beam. Also important is the factor that decomposition products resulting from the laser interaction not be a respiratory hazard. The purpose of a threshold limit evaluation is to define that point or distance where the barrier must be placed to withstand a worst-case exposure from the laser.

C3. Examples of Typical Laser System Classification and MPEs for Them

Laser classification was designed to include all types of lasers operating at essentially any wavelength or pulse duration, the rules of classification may appear complicated. To assist in the classification of commonly available lasers, Tables C1 and C2 have been prepared to aid the user in rapidly determining the required radiometric parameters needed to classify a laser and its applicable class once the required output parameters are known. Table C1 applies to CW lasers (potential exposure time 0.25 s), and Table C2 applies to pulsed lasers. To classify a repetitive-pulse laser, the values in Tables C1 and C2 are not generally applicable but may be used as a first step in estimating into what class the laser will fall.

In all cases the user should apply the rules given in Section 3 of the manual.

**Table C1. Typical Laser Classification –
Continuous Wave (CW) Point Source Lasers**

Wavelength (m)	Laser Type	Wavelength (m)	Class 1 * (W)	Class 2 (W)	Class 3 ** (W)	Class 4 (W)
Ultraviolet 0.180 to 0.280	Neodymium: YAG (Quadrupled) Argon	0.266	$\leq 9.6 \times 10^{-9}$ for 8 hours	None	> Class 1 but ≤ 0.5	>0.5
		0.275				
Ultraviolet 0.315 to 0.400	Helium-Cadmium Argon Krypton	0.325	$\leq 3.2 \times 10^{-6}$	None	> Class 1 but ≤ 0.5	>0.5
		0.351, 0.363, 0.3507, 0.3564				
Visible 0.400 to 0.700	Helium-Cadmium Argon (Visible)	0.4416 only	$\leq 4 \times 10^{-5}$ $\leq 5 \times 10^{-5}$ $\leq 1 \times 10^{-4}$ $\leq 2 \times 10^{-4}$	> Class 1 but $\leq 1 \times 10^{-3}$	> Class 2 but ≤ 0.5	>0.5
		0.457				
		0.476				
		0.488				
		0.514				
	Krypton Neodymium: YAG (Doubled) Helium-Neon	0.532	$\leq 4 \times 10^{-4}$			
		0.543				
	Dye Helium-Selenium	0.400 - 0.500	$\leq 0.4 \text{ CB} \times 10^{-4}$			
		0.460 - 0.500				
	Dye Helium-Neon InGaAlP Ti:Sapphire Krypton	0.550 - 0.700	$\leq 4 \times 10^{-4}$			
0.632						
0.670						
0.350 - 0.500						
0.6471, 0.6764						
Near Infrared 0.700 to 1.400	GaAlAs GaAlAs GaAs Neodymium: YAG Helium-Neon	0.780	$\leq 5.6 \times 10^{-4}$ $\leq 7.7 \times 10^{-4}$ $\leq 9.9 \times 10^{-4}$ $\leq 1.9 \times 10^{-3}$ $\leq 1.9 \times 10^{-3}$ $\leq 2.1 \times 10^{-3}$ $\leq 1.5 \times 10^{-2}$	None	> Class 1 but ≤ 0.5	>0.5
		0.850				
		0.905				
		1.064				
		1.080				
		1.152				
		1.310				
Far Infrared 1.400 to 10^3	InGaAsP InGaAsP Holmium Erbium Hydrogen Fluoride Helium-Neon Carbon Monoxide Carbon Dioxide Water Vapor Hydrogen Cyanide	1.550	$\leq 9.6 \times 10^{-3}$ $\leq 9.5 \times 10^{-2}$	None	> Class 1 but ≤ 0.5	>0.5
		2.100				
		2.940				
		2.600 - 3.00				
		3.390 only				
		5.000 - 5.500				
		10.6				
		118				
		337				

* Assumes no mechanical or electrical design incorporated into laser system to prevent exposures from lasting up to $T_{max}=8$ hours (one workday); otherwise the Class 1 AEL could be larger than tabulated.

** See 3.3.3.1 for definition of Class 3R.

**Table C2. Typical Laser Classification –
Single-Pulse Point Source Lasers**

Wavelength (μm)	Laser Type	Wavelength $\mu\text{(m)}$	Pulse Duration (s)	Class 1 (J)	Class 3B (J)	Class 4 (J)
Ultraviolet						
0.180 to 0.400	Excimer (ArF)	0.193	20×10^{-9}	$\leq 2.4 \times 10^{-5}$	} > Class 1 but ≤ 0.125	>0.125
	Excimer (KrF)	0.248	20×10^{-9}	$\leq 2.4 \times 10^{-5}$		
	Neodymium: YAG Q-switched (Quadrupled)	0.266	20×10^{-9}	$\leq 2.4 \times 10^{-5}$		
	Excimer (XeCl)	0.308	20×10^{-9}	$\leq 5.3 \times 10^{-5}$		
	Nitrogen	0.337	20×10^{-9}	$\leq 5.3 \times 10^{-5}$		
	Excimer (XeF)	0.351	20×10^{-9}	$\leq 5.3 \times 10^{-5}$		
	Visible					
0.400 to 0.700	Rhodamine 6G (Dye Laser)	0.450-0.650	1×10^{-6}	} $\leq 1.9 \times 10^{-7}$	} > Class 1 but ≤ 0.03	>0.03
	Copper Vapor	0.510, 0.578	2.5×10^{-9}			
	Neodymium: YAG (Doubled) (Q- switched)	0.532	20×10^{-9}			
	Ruby (Q-switched)	0.6943	20×10^{-9}			
	Ruby (Long Pulse)	0.6943	1×10^{-3}			
Near Infrared						
0.700 to 1.4	Ti: Sapphire	0.700-1.000	6×10^{-6}	$\leq 1.9 \times 10^{-7}$	} \leq	>0.033**
	Alexandrite	0.720-0.800	1×10^{-4}	$\leq 7.6 \times 10^{-7}$		
	Neodymium: YAG (Q-switched)	1.064	20×10^{-9}	$\leq 1.9 \times 10^{-6}$		
Far Infrared						
1.400 to 10^3	Erbium: Glass	1.540	10×10^{-9}	$\leq 7.9 \times 10^{-3}$	} > Class 1 but ≤ 0.125	>0.125
	Co: Magnesium- Fluoride	1.8-2.5	80×10^{-6}	$\leq 7.9 \times 10^{-4}$		
	Holmium	2.100	250×10^{-6}	$\leq 7.9 \times 10^{-4}$		
	Hydrogen Fluoride	2.600-3.000	0.4×10^{-6}	$\leq 1.1 \times 10^{-4}$		
	Erbium	2.940	250×10^{-6}	$\leq 5.6 \times 10^{-4}$		
	Carbon Dioxide	10.6	100×10^{-9}	$\leq 7.9 \times 10^{-5}$		
Carbon Dioxide	10.6	1×10^{-3}	$\leq 7.9 \times 10^{-4}$			

* Assuming that both eye and skin may be exposed, i.e., 1.0mm beam (area of limiting aperture = $7.9 \times 10^{-3} \text{ cm}^2$).

** Class 3B AEL varies from 0.033 to 0.480 J corresponding to wavelengths that vary from 0.720 to 0.800 m.

Table C3a. Point Source MPE for the Eye for Selected CW Lasers

Laser Type	Wavelength (μ m)	Exposure Duration (s)	Maximum Permissible Exposure	
			($J \cdot cm^{-2}$)	($W \cdot cm^{-2}$)
Argon	0.275	10 to 3×10^4	3×10^{-3}	—
Helium-Cadmium	0.325	10 to 3×10^4	1	—
Argon	0.351	10 to 3×10^4	1	—
Helium-Cadmium	0.4416	0.25	—	2.5×10^{-3}
Argon	0.488	10 to 58	—	1×10^{-3}
	0.488	58 to 10^2	5.8×10^{-2}	—
	0.488	$> 10^2$	—	5.8×10^{-4}
	0.5145	10 to 3×10^4	—	1×10^{-3}
Helium-Neon	0.632	0.25	—	2.5×10^{-3}
Helium-Neon	0.632	10 to 3×10^4	—	1×10^{-3}
Krypton	0.647	0.25	—	2.5×10^{-3}
Krypton	0.647	10 to 3×10^4	—	1×10^{-3}
InGaAlP	0.670	0.25	—	2.5×10^{-3}
GaAs	0.905	10 to 3×10^4	—	2.6×10^{-3}
Neodymium: YAG	1.064	10 to 3×10^4	—	5×10^{-3}
InGaAsP	1.310	10 to 3×10^4	—	4×10^{-2}
InGaAsP	1.550	10 to 3×10^4	—	0.1
Carbon-Dioxide	10.600	10 to 3×10^4	—	0.1

Table C3b. Point Source MPE for the Skin for Selected CW Lasers

Laser Type	Wavelength (μ m)	Exposure Duration (s)	Maximum Permissible Exposure	
			($J \cdot cm^{-2}$)	($W \cdot cm^{-2}$)
Argon	0.275	3×10^4	3×10^{-3}	—
Helium-Cadmium	0.325	10 to 1000	1	—
	0.325	> 1000	—	1×10^{-3}
Argon	0.351	10 to 1000	1	—
	0.351	> 1000	—	1×10^{-3}
Helium-Cadmium	0.4416	> 10	—	0.2
Argon	0.488	> 10	—	0.2
Argon	0.5145	> 10	—	0.2
Helium-Neon	0.6328	> 10	—	0.2
Krypton	0.647	> 10	—	0.2
GaAs	0.905	> 10	—	0.5
Neodymium: YAG	1.064	> 10	—	1.0
Carbon-Dioxide	10.600	> 10	—	0.1

**Table C4. Point Source MPE for the Eye and MPE
for the Skin for Selected Single-Pulse Lasers**

Laser Type	Wavelength (m)	Pulse Duration (s)	Maximum Permissible Exposure (J x c m ^{- 2})	
			Eye	Skin
Excimer (ArF)	0.193	2 x 10 ⁻⁸	3 x 10 ⁻³	3 x 10 ⁻³
Excimer (KrF)	0.248	2 x 10 ⁻⁸	3 x 10 ⁻³	3 x 10 ⁻³
Excimer (XeCl)	0.308	2 x 10 ⁻⁸	6.7 x 10 ⁻³	6.7 x 10 ⁻³
Excimer (XeF)	0.351	2 x 10 ⁻⁸	6.7 x 10 ⁻³	6.7 x 10 ⁻³
Ruby (Normal-Pulsed)	0.6943	1 x 10 ⁻³	1 x 10 ⁻⁵	0.2
Ruby (Q-switched)	0.6943	5 – 100 x 10 ⁻⁹	5 x 10 ⁻⁷	0.02
Rhodamine 6G dye laser	0.500 - 0.700	0.5 – 18 x 10 ⁻⁶	5 x 10 ⁻⁷	0.03 to 0.07
Nd:YAG (Normal Pulse)	1.064	1 x 10 ⁻³	5 x 10 ⁻⁵	1.0
Nd:YAG (Q-switched)	1.064	5-100 x 10 ⁻⁹	5 x 10 ⁻⁶	0.1
Carbon Dioxide	10.6	1 x 10 ⁻³	0.1	0.1

Appendix D

Guide for Organization and Implementation of Employee Laser Safety Training Programs

D1. Employee Training

D1.1 General. Education shall be provided to users of Class 1M, 2, 2M or 3R lasers by the appropriate PI or laser supervisor. Laser safety training shall be provided to users of Class 3B or 4 lasers through the Radiation Safety Office.

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

- (1) For personnel routinely working with or potentially exposed to Class 3B or 4 lasers:
 - (a) Fundamentals of laser operation (physical principles, construction, etc.)
 - (b) Bio-effects of laser radiation on the eye and skin
 - (c) Significance of specular and diffuse reflections
 - (d) Non-beam hazards of lasers (see Section 7)
 - (e) Laser and laser system classifications
 - (f) Control measures
 - (g) Overall responsibilities of Auburn University and employee
 - (h) Medical surveillance practices
 - (i) CPR for personnel servicing or working on lasers with exposed high voltages and/or the capability of producing potentially lethal electrical currents

D1.2.1 Class 2 and 2M Awareness Training. For Class 2 and 2M education, simple, brief training designed for easy implementation by the PI /laser supervisors. Topics may include:

- (1) Simple explanation of a laser
- (2) Compare difference of laser light from ordinary light
- (3) 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
- (4) Explain the differences between a Class 2 and 2M laser
- (5) Provide cautioning against intentionally staring into a Class 2 or 2M laser
- (6) General explanation of the differences in the various laser classifications

D1.2.2 Class 1M and 3R Awareness Training. For Class 1M and 3R education, simple brief training designed for easy implementation by the PI /supervisors. Topics include:

- (1) Simple explanation of a laser
- (2) Compare difference of laser light from ordinary light
- (3) Describe nature of near IR beams where applicable
- (4) Explanation of Class 1M and 3R lasers, and the relative potential hazard of each
- (5) Explanation of the potential for collecting and focusing optics to increase the hazard

Appendix E

Medical Examinations

E1. Medical Referral Following Suspected or Known Laser Injury

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

E1.1 Medical Examinations for Exposure Incidents. Recommended medical examinations for actual or suspected exposure include but are not limited to those specified in Section E3.

E2. Medical Surveillance Examinations

E2.1 Rational for Surveillance Examinations. The basic reasons for performing medical surveillance of personnel working in a laser environment are the same as for other potential health hazards. Physical fitness assessments are used to determine whether an employee would be at increased or unusual risk in a particular environment. For laser workers, the need for this type of assessment is likely to be determined by factors other than laser radiation per se. Specific info on medical surveillance requirements that might exist because of other potential exposures, (toxic gases, noise, ionizing radiation, etc) are outside the scope of this manual. Early detection of biological change / damage presupposes that chronic or subacute effects may result from exposure to a particular agent at levels below that required for acute injury. Active intervention must be possible to arrest further biological damage or to allow recovery from these effects. Although chronic injury from laser radiation in ultraviolet, near ultraviolet, blue portion of the visible, and near infrared regions appears theoretically possible, risks to workers using laser devices are primarily from accidental acute injuries. Based on risks involved with current laser uses, medical surveillance requirements that should be incorporated appear to be minimal. Other extensive medical surveillance arguments have been based on the fear that repeated accidents might occur and the workers would not report minimal acute injuries. The limited number of injuries reported in the past 30 years and the excellent safety records with laser devices do not provide support to this argument.

E3. Medical Examinations

E3.1 Preassignment Medical Examinations. Except for examination following suspected injury, these are the only examinations required by Auburn University.

One purpose is to establish a baseline against which damage (primarily ocular) can be measured in the event of an accidental injury. A second purpose is to identify certain workers who might be at special risk from chronic exposure to selected continuous wave lasers. For incidental workers (e.g., custodial, clerical and supervisors not working directly with lasers) only visual acuity measurement is required.

For laser workers medical history, visual acuity, and selected exam protocols are required.

E3.1.2 Periodic Medical Examinations. Periodic examinations are not required.

E3.2 Examination Protocols.

E3.2.1 Ocular History. The past eye history and family history are reviewed. Any current complaints concerned with the eyes are noted. Inquiry should be made into the general health status with a special emphasis upon systemic diseases which might produce ocular problems in regard to the performance cited in Section 6.1. The current refraction

prescription and the date of the most recent examination should be recorded.

Certain medical conditions may cause the worker to be at increased risk for chronic exposure.

Use of photosensitizing medications, such as phenothiazines and psoralens, lower the threshold for biological effects in the skin, cornea, lens and retina of experimental animals exposed to ultraviolet and near ultraviolet radiation. Aphakic individuals would be subject to additional retinal exposure from blue light and near ultraviolet and ultraviolet radiation.

Unless chronic viewing of these wavelengths is required, there should be no reason to deny employment to these individuals.

E3.2.2 Visual Acuity. Visual acuity for far/near vision should be measured with a standardized and reproducible method. Refraction corrections should be made if required for distant/near test targets. If refractive corrections are not sufficient to change acuity to 20/20 (6/6) for distance and near vision, a more extensive exam is indicated as defined in Section 6.3.

E3.2.3 Macular Function. Amsler grid or similar pattern is used to test macular function for distortions and scotomas. Test should be administered in a fashion to minimize malingering and false negatives. If distortions/missing portions of the grid pattern are present, test is not normal.

E3.2.4 Color Vision. Color vision can be documented by Ishihara or similar color vision tests.

E3.2.5 Examination of the Ocular Fundus with an Ophthalmoscope or Appropriate

Fundus Lens at a Slit Lamp. This portion of the examination is to be administered to individuals whose ocular function in any of Section E.3.2.1 through E.3.2.4 is not normal.

The points to be covered are: presence or absence of opacities in the media; sharpness of outline of the optic disc; color of the optic disc; depth of the physiological cup, if present; ratio of the size of the retinal veins to that of the retinal arteries, presence or absence of a well defined macula and presence or absence of a foveal reflex; and retinal pathology that can be seen with an ophthalmoscope (hyper-pigmentation, depigmentation, retinal degeneration, exudate, as well as any induced pathology associated with changes in macular function). Even small deviations from normal should be described and carefully localized. Dilation of the pupil is required.

E3.2.6 Skin Examination. Not required for preplacement examinations of workers; however, it is suggested for employees with history of photosensitivity or working with ultraviolet lasers. Previous dermatological abnormalities and family history are reviewed. Current complaints concerned with the skin are noted as is the history of medication usage, particularly those drugs which 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.

E3.2.7 Other Examinations. Further exams should be done as deemed necessary by examiner.

E4. Records and Record Retention

Complete and accurate records of all medical examinations (including specific test results) should be maintained for all personnel included in the medical surveillance program.

Records should be retained for at least 30 years.

E5. Access to Records

The results of medical surveillance examinations should be discussed with the employee. All non-personally identifiable records of the medical surveillance examinations acquired in Section E.4 of these guidelines should be made available on written request to authorized physicians and medical consultants for epidemiological purposes. The record of individuals will, as is usual, be furnished upon request to their private physician.

Appendix F

Non-Beam Hazards

Non-beam hazards may be categorized into physical, chemical, or biological agents. Physical agents include, but are not limited to electrical hazards, collateral and plasma radiation, noise, and mechanical hazards. Chemical agents may be subdivided into laser generated airborne contaminants (LGAC), compressed gases, dyes, and solvents. Biological agents include blood borne materials such as blood components and microorganisms.

F1. Physical Agents

F1.1 Electrical Hazards.

F1.1.1 Grounding. The frames, enclosures and other accessible non-current-carrying metallic parts of laser equipment should be grounded. Grounding should be accomplished by providing a reliable, continuous metallic connection between the part or parts to be grounded and the grounding conductor of the power wiring system.

F1.1.2 Electrical Fire Hazards. Components in electrical circuits should be evaluated with respect to potential fire hazards. Enclosures, barriers or baffles of nonmetallic material should comply with Underwriters Laboratory Standard, UL 746C, Polymeric Materials - Use in Electrical Equipment Evaluations.

F1.1.3 Electrical Hazards from Explosion. Gas laser tubes and flash lamps should be supported to ensure that their terminals cannot make any contact which will result in a shock or fire hazard in the event of a tube or lamp failure. Components such as electrolytic capacitors may explode if subjected to voltages higher than their ratings, with the result that ejected metallic material may bridge live electrical parts. Such capacitors should be rated to withstand the highest probable voltage should other circuit components fail, unless the capacitors are adequately contained so as not to create a hazard.

F1.1.4 Marking. User should ensure that each laser system is permanently marked with its primary electrical rating in volts, frequency, and power or current. User should also determine if the system has electrical components operating at other frequencies. This is important because the threshold for current-induced biological effects will vary with frequency.

F1.1.5 Other. Where applicable, user should comply with provisions of OSHA Standards for Electrical Safety-Related Work Practices (29 CFR 1910 Subpart S) and the Control of Hazardous Energy (lockout/tagout; 29 CFR 1910.147).

F1.2 Plasma and Collateral Radiation. Plasma radiation is produced when the output from an energetic laser beam interacts with target materials. This is demonstrated most often for pulsed emissions from CO₂ lasers when welding, drilling or treating metallics. Such plasma radiation is rich in actinic UV (UV-C and UV-B) and contains UV-A and visible wavelengths. Greatest concern for visible wavelengths is the blue-light component and the total luminance (photometric brightness) of the plasma. Studies have demonstrated potential overexposures to actinic radiation and blue light at distances ~ 1 meter from the beam-material interaction site. Luminance may exceed exposure at this distance, too. The acceptable exposure duration for actinic radiation during some evaluations has been shown to be less than a minute, but this depends on a number of factors including beam power, shield gas, and base material. Collateral radiation includes those wavelengths emitted by the laser or laser system other than laser radiation. An example of this is x-radiation emitted by a high-energy switch, such as a thyratron, in a pulsed laser. Collateral x-radiation is produced by the process known as bremsstrahlung, or braking radiation. This occurs when electrons, under a high difference in electric potential, are sharply accelerated resulting in the emission of x-rays. Broadband optical radiation may be produced by lamps used to energize (optically-pumped) solid-state

lasers. Radio-frequency radiation may be generated from energy-pumping components in some gas lasers, such as sealed plasma-tube CO₂ lasers, or from pulse-forming components in pulsed lasers. Power-frequency electric and magnetic fields (50 or 60 Hz and harmonics) are produced by electrical power supplies, wiring, and circuit components, for all alternating current lasers. As with plasma radiation, collateral radiation should be evaluated to determine the potential for overexposure, and appropriate control measures utilized as necessary.

F1.2.1 Control Measures. These include distance, shielding, and personal protective equipment. The intensity of the electromagnetic energy decreases with distance, usually decreasing with the second or third power of distance, which can effectively decrease exposure. Shielding is effective for optical, microwave, RF radiation and power-frequency electric fields. Much of the optical radiation band may be shielded with plastics such as polycarbonate and poly(methyl methacrylate)-type plastics, although additives (dyes) may be necessary for visible and some IR wavelengths. Microwaves and electric fields may be shielded with conductive materials (e.g., metals such as aluminum or copper). Shielding is more difficult for low-frequency RF and power-frequency magnetic fields, which may require the use of special shielding materials, such as ferrous alloys containing nickel or cobalt. Personal protective equipment, for the eyes and skin, is useful for optical radiation. In general, personal protective equipment is not useful for RF and power-frequency fields.

F1.3 Noise. Some pulsed lasers may present a potential noise hazard. This has occurred with certain excimer lasers and transversely-excited atmospheric (TEA) carbon dioxide lasers. The LSO should request information on potential noise exposure or equipment sound levels from the laser product manufacturer. In many cases, sound levels will not result in overexposure to noise, but may be a nuisance that must be addressed.

F2. Chemical Agents

F2.1 Laser Generated Airborne Contaminants (LGAC). LGAC may be aerosols, gases or vapors. Factors in the generation of LGAC include the base material, shield gas, and beam irradiance. In general, if the beam irradiance exceeds 107 W/cm², the intensity is sufficient to produce LGAC from most target materials, (Table F 1(a)), although beam irradiance values of hundreds of W/cm² have been reported to produce LGAC (Table F 1(b)). Aerosols, generated by absorption of laser radiation, will vary in size, composition, morphology and toxicity. Generally, size distribution is usually weighted towards aerosols that are small, and are, therefore, respirable. The LGAC aerosol, metallic oxide fumes, comes from laser processing of metals. If the metal is mild steel, the major aerosol will be iron oxides. If certain stainless steels, the aerosol will include oxides of iron, nickel, and chromium.

Gases/vapors forming during laser beam interaction may be representative of the base material, such as the monomer from which a polymer is synthesized. In other cases, the base material may dissociate and reactions may produce new compounds. Some compounds include: polycyclic aromatic hydrocarbons (PAH) from mode burns on methyl methacrylate-type polymers; hydrogen cyanide & benzene from cutting of aromatic polyamide fibers; fused silica from cutting quartz; and hydrogen chloride & benzene from cutting PVC. For a more complete list see Table F 1(b). For biological effects / control measures see Table F 1(c).

F2.1.1 Control Measures. Engineering control measures should be given priority for LGAC control measures. Foremost among these are isolation, the use of local exhaust ventilation, and the substitution of substances that produce less toxic by-products (Section 7.3.1).

F2.2 Compressed Gases. Common laser gases may be inert (helium-neon, argon), flammable (hydrogen), toxic (chlorine, fluorine), corrosive (hydrogen chloride), or oxidizing (oxygen). The potential hazard(s) associated with a specific gas or gas mixture must be addressed, and some potential hazards may not be obvious. For example, toxic gases may be diluted (typically less than a few percent) in biologically inert gases. However, if released to the atmosphere, the dilute concentration may result in airborne concentrations that are

immediately dangerous to life and health (IDLH). Consider that a gas mixture for some carbon dioxide lasers includes 2% carbon monoxide, which equals 20,000 parts per million (ppm). If released to the atmosphere, this would be well above the IDLH level for CO, which is 1200 ppm. Also, in sufficient quantity, the inert gases may produce an adverse biologic effect, simple asphyxiation by displacement of the available oxygen.

F.2.2.1 Control Measures. Prior to installing a gas system, the LSO should consider elements of design and control. Including, but not limited to: cylinder location & security; regulator selection; purge system; ventilation requirements; and remote operation: including emergency shutoff, personal protective equipment, labeling, and employee training.

F2.3 Laser Dyes and Solvents. There is potential exposure to dyes during weighing & mixing, and during decontamination of the system. There is potential exposure to solvents during transfer processes. Exposure to both dyes and solvents exists during mixing, spill clean up, and disposal. Laser dyes include xanthenes, polymethines, coumarins, and stilbenes. Acute toxicity studies have demonstrated that a number of these dyes are poisons, where the dose lethal to 50% of the test animals (LD₅₀) was less than 50 mg/kg. And, bioassays have shown that some dyes are mutagenic. Solvents used with dyes are organic compounds that are relatively common in research. These solvents may pose a wide variety of possible health hazards, including those of both a chemical (e.g., toxicity) and physical (e.g., fire) nature.

F.2.3.1 Control Measures. If more than one solvent can be used for a given application, the solvents should be compared with ensure that the safest is selected. The information necessary to aid in this determination is often contained in the material safety data sheet (M SDS). For example, the user should compare acute toxicity data (often in the form of the LD₅₀), exposure limits (e.g., threshold limit values = ACGIH TLVs; or permissible exposure limits = OSHA PELs), volatility (vapor pressure), and flammability (flash point).

The LSO must address control measures appropriate for mixing and use of dyes and solvents, too. This includes, but is not limited to, methods of solvent transfer, adequate ventilation, personal protective equipment, process isolation, provision of secondary containment, path and construction of tubing or piping, labeling and employee training. Some useful information on control measures for dye/solvent systems has been developed by Lawrence Livermore National Laboratory and is included in the reference section, below.

F3. Biological Agents

Lasers may be used in surgery in the veterinary environment. This creates the potential for the generation of LGAC and airborne infectious materials, when the beam interacts with tissues.

F3.1 LGAC. LGAC in the laser plume may be aerosols, gases or vapors. Gaseous materials may be numerous, but of special interest are benzene, formaldehyde, and hydrogen cyanide. Condensable phases may include PAHs such as benzo(a)pyrene. And, LGAC may be generated if the beam contacts articles in the health care environment, (tubing or swabs).

F3.2 Infectious Materials. The laser plume may contain aerosolized blood (plasma and blood cells or fragments of cells) and blood borne pathogens. Blood borne pathogens may include bacteria and viruses. Viral organisms that have been found include a bacteriophage and human papillomavirus. In vitro studies of bacterial targets demonstrated viable *Escherichia coli* and *Staphylococcus aureus* in the laser plume.

F3.3 Control Measures. The primary control measure is exhaust ventilation; specifically smoke evacuation. Most smoke evacuation units are movable units that include a small, high-velocity nozzle (hood) that can be located very near the laser-tissue interaction site. The collected effluent is conveyed to the filtration system which includes an activated carbon bed for organic LGACs and a HEPA (high efficiency particulate air-) or ULPA (ultra-low particulate air-) filter for aerosols. In some cases, the source of exhaust ventilation may be a house vacuum system. Regardless of the type of system, the LSO should ensure that the filtration system is on a preventative maintenance schedule so that filter penetration does not occur.

Table F1a. Laser Generated Air Contaminant (LGAC) Thresholds

Approximate LGAC Thresholds and Guide to the Determination of Air Monitoring				
Irradiance (W cm ⁻²)	Plastic	Composites	Metals	Skin
> 10 ⁷	X	X	X	X
10 ³ to 10 ⁷	X	Δ	Δ	Δ
< 10 ³	O	O	O	O

Notes:

X - can exist

Δ - may exist

O - probably do not exist

Table F1b. Laser Generated Airborne Contaminants

Operational Parameters	Decomposition Products	Comment	Reference
Industry and Research			
15 to 25 W CO ₂ on PVC, nylon & PMMA	PMMA: methyl methacrylate monomer; PVC: HCl, benzene, toluene, styrene, PAHs; nylon: volatile amides	Analyzed gaseous material	Rockwell et al., 1976
1.6 kW CO ₂ on PVC; shield gas: air or Ar	Benzo(a)pyrene, pyrene, fluoranthene, o-terphenyl pyrrolsates, 1-methylpyrene, more	Condensed-phase material	Kokosa & Doyle, 1985
2.5 kW CO ₂ on Kevlar; shield gas: He	Benzene, styrene, pyrene, benzo(k)fluoranthene, chrysene/benz(a)anthracene, biphenyl, fluorene, other PAHs	Between 0.25 & 0.062 mg of benzene per inch of cut material	Doyle & Kokosa, 1986
10 kW CO ₂ on steel and concrete	Cr, Ni, Fe	SS 304; evaluated aerosols	Tarroni et al., 1986
CW CO ₂ on PVC, polyester, Kevlar, leather, mild steel	Typically < 90% of aerosol is smaller than 1 μm; SS 347: Cr & Ni oxides; galvanized steel: Fe & Zn oxides; nonmetals: CO, benzene, toluene, others	Includes discussion of exhaust ventilation	Ball et al., 1988
1 kW CO ₂ on graphite composite materials; shield gases: air or Ar	Aniline, cresols, quinoline, 1,1-biphenyl, dibenzofuran, phenanthrene, many more	Base materials were epoxy & polyimide-based	Kwan, 1990
350W CO ₂ on Kevlar & Kevlar-graphite	CO, HCN, NO, NO ₂ , 1,1,1-trichloroethane, ethyl acetate; methyl isobutyl ketone	Workplace survey; no overexposures found	Moss & Seitz, 1990

Table F1b. Laser Generated Airborne Contaminants (cont.)

Operational Parameters	Decomposition Products	Comment	Reference
600 W CO ₂ on fused quartz, PMMA, ABS	Fused silica from quartz; ethyl acrylate from polymers	Personal & area samples	Fleeger & Moss, 1990
2.5 kW CO ₂ on Al, carbon steel, SS, PMMA-plastics	C-steel: Fe oxides; SS: Cr oxides, others; plastics: benzene, pyrene, toluene, PAHs	Identified hexavalent Cr from SS	Hietanen et al., 1992
900 W CO ₂ on mild steel & SS	SS: Fe > Fe ₂ O ₃ > Cr > Cr ₂ O ₃ > Ni > NiO	Diameter of projected particles ranged in size from 50 to 500 μm	Powell et al., 1993
25.9 W CO ₂ on felt, woven fabrics, PVC, PMMA, acrylic, Formica	Felt: formaldehyde, HCN, acrylonitrile, acetonitrile, acrolein; Fabric: formaldehyde, HCN, benzene, styrene; Formica: formaldehyde, HCN, methanol, acetonitrile, furan; others	Area air samples: CO levels low (2 ppm) for all materials	Kiefer & Moss, 1997
2.6 kW CO ₂ on SS; assist gas: N ₂ or O ₃	Operational parameters related to highest fume concentration: N ₂ : speed; O ₂ : power	2 mm thick SS	Siggard & Olsen, 1997
750 W CO ₂ on carbon steel, galvanized steel and SS	Generally, 75-80% of particles < 3 μm in diameter	Concentration of airborne samples can exceed magnitude of exposure limits	Pena et al., 1998
280 to 300 W Nd:YAG; 2.2-5 kW CO ₂ ; both on SS & Zn-coated steel	Respirable dust concentrations 0.12-0.76 mg/m ³ (Nd:YAG) & 0.22-2.30 mg/m ³ ; airborne metals: Fe, Zn, Mn, Cr,	Exposure limits not exceeded for dust or elements	Klein et al., 1998
Degradation of ZrSe infrared optical components	Possibly ZnO, SeH ₂ , SeO ₃ or H ₂ SeO ₃ ; Th compounds may be released	Laser-induced degradation & damage	Dahmen et al., 1995
2.5 kW CO ₂ welding on steel and Al; shield gas: Ar	Steel: 0.21 mg/s O ₃ & 0.88 mg/s NO _x ; Al: 0.72 mg/s O ₃ & 3.62 mg/s NO _x	O ₃ concentration quickly increased above exposure limit	Schroder et al., 1997
Pulsed KrF excimer (248 nm) on polymer-based thin films & unfired ceramics	Polymer-based films: majority of particles <0.1 μm; ceramic: particle diameters between 0.5 and 5 μm	Analyzed by scanning electron microscopy and shadow photography	Thomas & Scott 1995
Health Care			
1 kJ Nd: glass on animal tumors	Projectile particulate matter may reach an initial velocity of 5000 feet per second	Discusses control measures	Wilkinson, 1969

Table F1b. Laser Generated Airborne Contaminants (cont.)

Operational Parameters	Decomposition Products	Comment	Reference
KrF, XeCl & CO ₂ on atherosclerotic plaque	Liquid or fibrous plaques: lipids, proteins, diene & triene hydroperoxides of fatty acids, water: main product for UV lasers	<i>In vitro</i> experiment	Furzikov et al., 1987
5 to 30 W CW Nd:YAG & 10 to 20 W CO ₂ (pulsed) on pig tissue	Aerosol concentration highest 20 cm above surgical site; VOCs: toluene, styrene, ethylbenzene, benzaldehyde, 2-butanone, pyrrole/pyridine, others	VOC concentrations relatively low; aerosol concentration relatively high	Wasche & Albrecht, 1988
300 W CO ₂ on beef liver 30 W Nd:YAG	Benzene, smoke, acrolein, formaldehyde, PAHs Composition similar to CO ₂ laser, above	Irradiance as low as 380 W/cm ² produce LGAC	Kokosa & Eugene, 1989
30 W CO ₂ on pork chop 38 to 74 W Nd:YAG on pork chop 4WCO ₂ , 2.5 W Ar laser	Acetone, isopropanol, toluene, cyclohexane, alkanes, formaldehyde, HCN, Ethanol, isopropanol, cyclohexane, toluene, alkanes, methyl isobutyl ketone, formaldehyde Formaldehyde	Laboratory evaluation Laboratory evaluation Procedure on patient	Moss et al. 1990
CO ₂ & XeCl on pig tissues	Ethene, propene, benzene, methyl-1-propene, toluene, cis-2-butene, acetonitrile, 2-propenenitrile, others	<i>In vitro</i> experiment	Weigmann et al., 1996
200 mJ Er:YAG, 40 mJ XeCl, 10 W CO ₂ & 20 W Nd:YAG on dental materials, pig tissue, and agar gels	Particle velocities on the order of hundreds of m/s for pulsed ablation; some m/s for CW ablation	Size distribution & morphology depend on laser type & material	Treffler et al., 1996
6-45 W CO ₂ on agar targets seeded with 2 bacteria	Viable <i>Escherichia coli</i> & <i>Staphylococcus aureus</i>	<i>In vitro</i> experiment found <i>S. aureus</i> to be more resistant to laser thermal effects	Byrne et al., 1987
Er:YAG on agar target	Viable bacteriophage 174 transported in the plume	<i>In vitro</i> experiment	Ediger & Matchette, 1989

Table F1b. Laser Generated Airborne Contaminants (cont.)

Operational Parameters	Decomposition Products	Comment	Reference
10 W CO ₂ on (HPV) plantar warts on patients & bovine warts (BVP)	Viral DNA found in plume but infectivity not ascertained	Procedure on patient (HPV); <i>in vitro</i> experiment (BPV)	Sawchuk et al., 1989
CO ₂ on genital HPV infections	Viral DNA dispersed by laser therapy	Procedure on patients	Ferenczy et al., 1990
20 W CO ₂ on HIV-infected cells in Petri dish	HIV pro-viral DNA	<i>In vitro</i> experiment	Baggish et al., 1991
4.3 W CO ₂ & 1.2-6.8 W Ar laser on agar bacteriophage substrate	Dispersion of viable bacteriophage 174 with airborne particles that settle within 100 mm of beam interaction site	<i>In vitro</i> experiment	Matchette et al., 1991
5 W CO ₂ on agar-bacteriophage substrate	Viable bacteriophage 174 contained in the plume	<i>In vitro</i> experiment	Matchette et al., 1993
0.5 J/cm ² CO ₂ laser on skin (resurfacing)	5 of 13 cultures were positive for <i>Staphylococcus</i> ; 1/5 had growth of <i>Corynebacterium</i> & 1/5 had growth of <i>Neisseria</i>	Plume & debris from 13 patients receiving laser resurfacing	Capizzi et al., 1998
60 mJ, pulsed Er:YAG on supernatants from a cell line producing retroviruses carrying a marker gene	Viral marker gene detected in 16% of samples at distances of 5.0-6.3 cm and 59% of samples 0.5-1.6 cm from laser impact	<i>In vitro</i> experiment	Ziegler et al., 1998

Abbreviations: ABS – acrylonitrile-butadiene-styrene; Al – aluminum; Ar – argon; BVP

□ bovine papillomavirus; Fe – iron; CO – carbon monoxide; CO₂ – carbon dioxide; Cr – chromium; DNA – deoxyribonucleic acid; Er:YAG – erbium:YAG; He – helium; HCN

□ hydrogen cyanide; HIV – human immunodeficiency virus; HPV – human papillomavirus; KrF – krypton fluoride; mg – milligrams; Mn – manganese; N₂ – nitrogen; Nd:YAG – neodymium:YAG; Ni – nickel – NO – nitric oxide; NO₂ – nitrogen dioxide; O₃ – ozone; PAHs- polycyclic aromatic hydrocarbons; PMMA – poly(methyl methacrylate); ppm – parts per million; PVC – poly(vinyl chloride); SS – stainless steel; Th – thorium; VOCs – volatile organic compounds; XeCl – xenon chloride; Zn – zinc; ZeSe – zinc selenide.

Table F1c. Control Measures for Laser Generated Air Contaminants (LGAC)

IRRADIANCE (W cm ⁻²)	POTENTIAL BIOLOGICAL EFFECTS	POSSIBLE CONTROL MEASURES
> 10 ⁷	Air contaminants assoc. with chronic effect	Process isolation Local exhaust ventilation Training and education Limit worker access Robotic/manipulators Housekeeping Preventive maintenance
10 ³ to 10 ⁷	Air contaminants assoc. with acute effects; noxious odors; visibility concerns	Local exhaust ventilation Respiratory protection Personal protective equip Preventive maintenance Training and education
< 10 ³	Potential for light odor	Adequate building ventilation Information

Appendix G Sample Laser SOP

(NOTE: This is a sample SOP. It must be adapted to apply to your specific lab and laser system. Feel free to add to the items, or to describe them in your own style. Just be sure to address all of the issues in this sample. (You are encouraged to delete the notes in these parentheses; they are included for your info in writing this SOP.))

Auburn University
Laser Safety Program
Laser Safety Standing Operating Procedure (SOP)

Department/College: _____ Date: _____

- This SOP shall be read and signed annually, and after any modification of the system, by all persons who use the laser system.
- This SOP shall be reviewed annually by the Primary Investigator (PI) to ensure it reflects the current conditions of the laser system.
- This SOP shall be readily accessible and available for reference by operators

1. LASER SAFETY CONTACTS

Lab Supervisor: _____

Phone: _____ After hours: _____

Primary Investigator: _____

Phone: _____ After hours: _____

University Laser Safety Officer: Michael R. Anderson

Phone: 844-6238 After hours: 750-9010

Medical Emergency: _____

Phone: _____ After hours: _____

2. LASER DESCRIPTION

(Briefly describe your laser system.)

a. All Class 3b and 4 lasers must be inventoried with Risk Management and Safety (RMS). The form to register your laser's description is located in the Laser Safety Manual, on the Auburn University website under academics and then Risk Management and Safety,

b. Attaching a completed copy of this form for each laser that makes up this system will satisfy this requirement.

c. Specific non-Beam Hazards of this laser system (check all that apply)

- Chemicals (dyes, solvents, etc.); attach MSDS if applicable
- Electrical (high voltage, current, etc.)
- Laser Generated Air Contaminants
- Compressed gases or cryogenic liquids
- Fire/ignition source
- Other (specify): _____

Describe control measures for any item checked above:
(Use as much space as needed.)

3. LASER SAFETY PROGRAM

See the AU Laser Safety Manual for:

- Responsibilities of the laser operator/user, lab supervisor, P.I., and LSO.
- Laser permitting requirements.
- SOP, Interlocks, and Training requirements.
- Eyewear requirements.
- Sign and labeling requirements.
- Non-radiation hazards.

4. LASER ENVIRONMENT

Define and attach a layout of the laser controlled area. Show the beam path and location (relative height and direction of travel) in relation to the user.

Define the targets.

5. OPERATING AND SAFETY PROCEDURES

A. Target area preparation (Describe items to be aware of, and steps for alleviating them prior to start up of system. (i.e., removing jewelry and watches from operator/ spectators; removing reflective objects that might possibly intersect beam; checking beam stops; etc.))

B. Start up procedures (including the manufacturer's recommended steps and the point at which the laser protective eyewear must be donned).

C. Operating procedures (power settings, Q-switched mode, pulse rate, other; for normal use of the system.)

D. Shut down procedures.

E. Special procedures (alignment, safety tests, maintenance tests, other as needed).

F. Emergency procedures. (Include procedures for evacuations, locations of emergency procedure posting, location of safety equipment (eyewash, safety shower, fire extinguisher, etc.) (This list will be short at first, and should grow as you encounter unusual situations.)

6. PERSONNEL PROTECTIVE EQUIPMENT (PPE)

Eyewear:

List the type of eyewear to be used with your laser system. NOTE – The Optical Density (OD) of the eyewear used in aligning your laser may not be the same OD as the eyewear used while operating your laser under normal conditions.

Eyewear is required to be inspected every year by the operator, and the results documented.

Other PPE: List any other PPE required by your system (such as: long sleeves, nitrile gloves, and face shields for UV lasers)

Appendix H PI APPLICATION FOR LASER USE

Auburn University

Principal Investigator *	Email (AU User Name)	AU Mailing Address
Department	AU & After Hours Telephone Numbers	Location (Bldg & Rm) of Use

*A Principal Investigator applying for first Auburn University permit must also submit a typed statement of laser training and experience.

Laser System Description

Manufacturer	Model	Serial Number	
Type (e.g. He-Ne, ND:YAG)	Class- 1,1M, 2, 2M, 3R,3B, 4)	Type beam (e.g., CW, pulsed)	Wavelength(s) (nm)
Beam diameter at aperture: _____ (mm)		Beam divergence: _____ (mrad)	
CW Laser Information Average Power: _____ (W) Maximum Power: _____ (W)		Pulsed Laser Information Pulse duration: _____ (sec) Pulse frequency: _____ (Hz) Average Joules / pulse: _____ (J) Maximum Joules / pulse: _____ (J)	

Proposed Use [e.g., holography, alignment, etc. Provide sufficient detail for Radiological Safety Committee evaluation. Attach additional pages if necessary.]

Please check all items that apply:

Use of Cryogens: _____	Laser Cutting / Welding: _____
Use of Compressed Gases: _____	Use of Pumping Laser: _____
High Voltage Power Supplies: _____	Beam Focusing Optics: _____
High Voltage > 30 kVp: _____	Frequency Doubling Crystal: _____
Dye Laser: _____	Tunable Laser: _____
Exposed Beam Paths: _____	Invisible Beam: _____
High Noise Levels: _____	Laser Fabricated / Modified at Auburn: _____

Names of persons using laser under your supervision

Certification

I certify that the laser will be used as described in this application and that all applicable provisions of the Alabama Department of Public Health Rules, Auburn University Laser safety policies, and specific approval conditions required by the Radiological Safety Committee, now or hereafter in effect, will be observed.

Signature of Principal Investigator

Date

Departmental Approval

Signature of Head of Department

Date

If you have questions about this form, please call Risk Management & Safety at 4-6238. After completion, please return this form to Laser Safety

Radiological Safety Site Review	
Have all operators / users received training?	Yes ____ No ____ N/A ____
SOP and Safety Guidelines established for this use?	Yes ____ No ____ N/A ____
Door have proper sign?	Yes ____ No ____ N/A ____
Equipment labeled with laser parameters?	Yes ____ No ____ N/A ____
Access to room controlled?	Yes ____ No ____ N/A ____
Warning devices used when laser is energized?	Yes ____ No ____ N/A ____
System interlocks used?	Yes ____ No ____ N/A ____
Proper eye protection provided?	Yes ____ No ____ N/A ____
Adequate room illumination?	Yes ____ No ____ N/A ____
Reflective surfaces in room controlled?	Yes ____ No ____ N/A ____
Elements in the beam path secured?	Yes ____ No ____ N/A ____
Radiological Safety Committee Approval Conditions	
Interim Review by Laser Safety Officer	
<input type="checkbox"/> Approved <input type="checkbox"/> Not approved <div style="float: right; width: 60%;"> <i>Signature of Laser Safety Officer</i> _____ <i>Date</i> _____ </div>	
Final Action by Radiological Safety Committee	
<input type="checkbox"/> Approved <input type="checkbox"/> Not approved <div style="float: right; width: 60%;"> <i>Signature of Radiological Safety Committee Chair</i> _____ <i>Date</i> _____ </div>	
Permit Number	Valid Until