TB MED 524

TECHNICAL BULLETIN

OCCUPATIONAL AND ENVIRONMENTAL HEALTH

CONTROL OF HAZARDS TO HEALTH FROM LASER RADIATION

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HEADQUARTERS, DEPARTMENT OF THE ARMY

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TECHNICAL BULLETIN
MEDICAL 524

HEADQUARTERS
DEPARTMENT OF THE ARMY
Washington, DC, 31 January 2006

CONTROL OF HAZARDS TO HEALTH FROM LASER RADIATION

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* This bulletin supersedes TB MED 524, 20 June 1985

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CHAPTER 1

BACKGROUND

1–1. Purpose

a. This bulletin provides guidelines and establishes procedures for personnel protection from laser radiation within the framework of currently documented experimental evidence. Medical guidance is limited to biological data available. This bulletin encompasses the portion of the electromagnetic spectrum in which laser radiation can be produced including: ultraviolet (UV), visible light, and infrared (IR) radiation.

b. This bulletin applies to those activities established and operated at active Army, Army National Guard/Army National Guard of the United States, U.S. Army Reserve, Department of the Army (DA) personnel, and Corps of Engineers facilities.

c. Provisions of this publication are subject to the latest editions of three international standardization agreements (STANAG): STANAG 2900, STANAG 3606, and STANAG 3828 found in appendix A.

d. It is Army policy to follow guidance in the American National Standards Institute (ANSI) Z136 series of standards. Additional guidance is contained in this document for U.S. Army laser systems used both indoors and outdoors for laser research, training, and tactical and strategic applications. Consult Military Handbook (MIL–HDBK)–828A for specific guidance on fielded military laser systems found in appendix A.

e. The evaluation of laser hazards often requires highly technical calculations by experienced individuals. See appendix B for sample calculations of potential hazards. Detailed technical information for highly specialized laser applications may be found in MIL–HDBK–828A. Assistance in the control of laser hazards on a range is available from the Laser/Optical Radiation Program (LORP) at the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM), ATTN: MCHB–TS–OLO, 5158 Blackhawk Road, Aberdeen Proving Ground, MD 21010-5403 or electronically at: http://chppm-www.apgea.army.mil/laser/laser.html.

1–2. References

Required and related publications and prescribed and referenced forms are listed in appendix A.

1–3. Explanation of abbreviations and terms
Abbreviations and special terms used in this bulletin are explained in the glossary.

1–4. Responsibilities

a. The Surgeon General will evaluate potential health hazards to personnel operating, testing, or associated with lasers. (See Army Regulation (AR) 10–5.)

b. The installation Laser Safety Officer (LSO) and/or Radiation Safety Officer (RSO) will—

(1) Be trained in laser safety by taking a laser hazards course such as offered by the USACHPPM LORP.

(2) Ensure that the medical surveillance guidance provided in appendix C is followed.

c. The Commander, USACHPPM will—

(1) Provide a team to investigate an alleged exposure to laser radiation when directed to do so by The Surgeon General.

(2) Establish the nominal ocular hazard distance (NOHD) of the standard fielded lasers.

(3) Determine minimum necessary optical density (OD) requirements for standard fielded lasers.

d. The USACHPPM LORP will—

(1) Provide specific guidance for all Force-on-Force training exercises for hazard assessment to ensure safety of personnel if Class 3b or Class 4 lasers are used. Contact the USACHPPM LORP at http://chppm-www.apgea.army.mil/laser/laser.html for guidance on Force-on-Force training operations.

(2) Evaluate any health hazards associated with the development of Army materiel including commercial off-the-shelf (COTS) laser devices.

(3) Perform any necessary health hazard analyses in order to minimize any potential hazardous exposures to laser/optical systems. Effective 28 November 1995, the USACHPPM was appointed lead agent for the Army Health Hazard Assessment Program. (See AR 40–10).

e. The Director, U.S. Army Medical Research Detachment - Walter Reed Army Institute of Research (USAMRD–WRAIR), Ocular Hazards Research will conduct research and development to obtain data on biomedical effects of laser radiation.

f. Installation commanders will perform responsibilities set forth in AR 11–9 and AR 385–63.

g. The command safety manager will perform responsibilities set forth in AR 385-10 and AR 385–63.

h. Firing/lasing unit commanders will perform responsibilities set forth in AR 11–9, AR 385–63, Department of the Army Pamphlet (DA Pam) 385–63, MIL–HDBK–828A, and Joint Publication (JP) 3–09.1.

i. The laser range safety officer/laser range safety noncommissioned officer (LRSO/LRSNCO) will ensure that all personnel authorized to participate in the laser operation are thoroughly instructed regarding safety precautions to be followed. See appendix D for safety guidelines to—

(1) Ensure that established target areas, with buffer zones around the target area as defined by the greatest laser-to-target distance, are observed.

(2) Provide adequate surveillance of the target area to ensure that unauthorized personnel do not enter the target area.

(3) Ensure that communication with personnel in the target area is maintained and that required protective eyewear is worn during the operation of the laser system.

(4) Report immediately to the LSO/RSO any suspected eye injury due to laser radiation so that an examination and care can be provided as soon as possible (within 24 hours of the exposure). See appendix C for information concerning medical surveillance.

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CHAPTER 2

INTRODUCTION TO LASERS

2–1. Background

a. The term Laser is an acronym derived from Light Amplification by Stimulated Emission of Radiation. The effects of laser radiation are essentially the same as optical radiation that is generated by more conventional UV, IR, and visible optical sources. The biological implications attributed to laser radiation usually result from the very high beam collimation, beam intensities, and monochromaticity of many lasers. Lasers differ from conventional sources of optical radiation primarily in their ability to attain highly coherent radiation (that is, light waves in phase). The increased directional intensity of the optical radiation generated by a laser results in concentrated optical beam irradiances at considerable distances.

b. Recent developments in laser technology have resulted in an increase in the use of these devices for military research and field use. Field military lasers are used primarily for target acquisition, training, and fire control. These lasers are termed rangefinders, target designators and direct-fire simulators. The widespread use of laser systems increases the probability of personnel exposure to injurious levels of laser radiation. Although lasers have useful characteristics, they are potentially hazardous, and adequate safeguards must be provided. Laser radiation should not be confused with ionizing radiation (that is, X-ray and gamma rays).

c. Lasers also perform a variety of non-military functions and come in many shapes and forms. Dangerous lasers can be smaller than a pen or larger than a truck and can be every size and shape in between. Lasers are also being used in communications, precision distance measurements, guidance systems, metalwork, photography, holography, and medicine.

d. The term laser is applied to devices that operate from stimulated emission with an output wavelength usually between approximately 100 nanometers (nm) and 1 millimeter (mm). Most lasers operate in one or more of the following output temporal modes (para 2–9):

(1) Continuous wave (CW).

(2) Pulsed, including: single-pulsed, Q-switched, mode-locked, and repetitively pulsed.

2–2. Nature of light

a. The word light as properly used refers to that portion of the electromagnetic spectrum that produces a visual effect. It was first shown by James Clerk Maxwell in 1873 that light is electromagnetic radiation that propagates at approximately 3×10^8 meters per second (m/s) in vacuum. Albert Einstein later postulated that the velocity of light in vacuum was constant and independent of the frame of reference throughout the universe and is the ultimate speed at which energy may be transmitted. The independence of the speed of light in vacuum has been verified experimentally numerous times.

b. Quantum mechanics was developed to describe the experimentally observed phenomenon that energy interacts with matter in discrete steps. Energy can be considered to consist of quanta (packets) of energy, called photons. The amount of energy (Q), represented by one photon, is proportional to the electromagnetic wave frequency (ν), with the proportionality constant being Planck's constant (h)—

$$Q = h\nu$$

c. Scientists have made use of almost the entire electromagnetic spectrum from zero hertz (Hz) (such as direct current from storage batteries) to 10^{24} hertz (Hz) (the very hard X-rays used for nondestructive inspection of metal parts). Figure 2–1 shows the electromagnetic spectrum and some of its uses and properties.

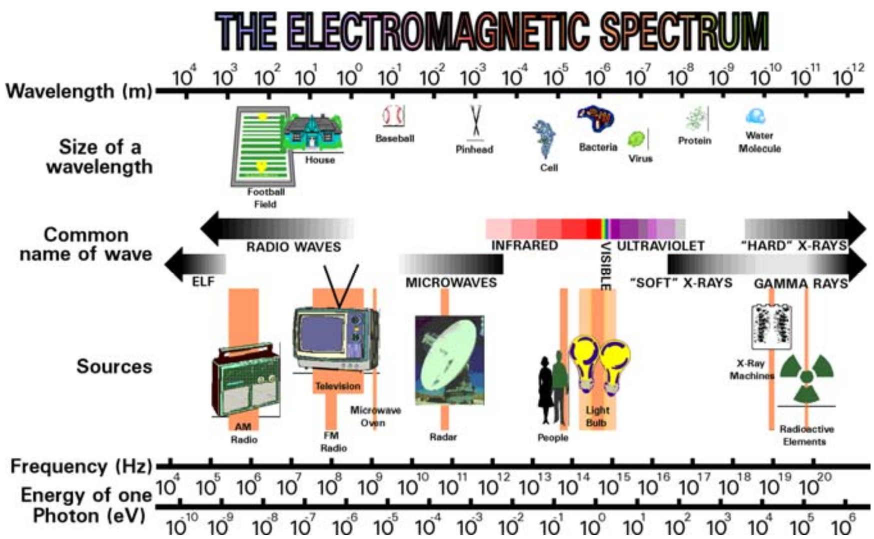


Figure 2–1. The electromagnetic spectrum

2–3. Production of light

a. Electromagnetic radiation, in the form of photons, is emitted whenever a charge is accelerated. This happens, for example, every time an electron drops from a higher energy state to a lower energy state in an atom, ion, or molecule (see figure 2–2). The energy of the photon is proportional to the change in energy of the atom, ion, or molecule.

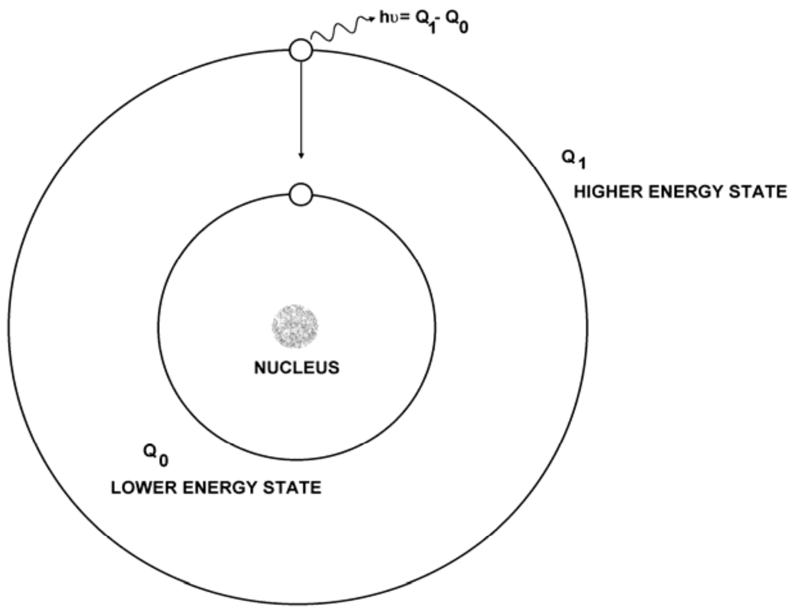


Figure 2–2. Emission of radiation by transmission of an electron from a higher energy state to a lower energy state

b. In ordinary light sources, electron transitions from higher energy states to lower energy states occur randomly and spontaneously, and one photon has no correlation with another. In a laser, however, these transitions are stimulated by other photons of exactly the same energy, wavelength, phase, and direction.

c. Electrons must be raised to higher energy levels before they can make the transition to lower energy levels and emit photons. There are many ways in which electrons can be raised to higher energy levels or become "excited," such as—

(1) Heating, as in the filament of an incandescent lamp.

(2) Collisions with other electrons, as in a fluorescent lamp discharge or in a television picture tube.

(3) Absorbing energy from photons, as in luminescent paint on a watch dial.

(4) Chemical reactions, as in a flame.

d. In addition to the familiar electronic energy levels, laser action can also result from vibrational and rotational energy levels of molecules, as in the carbon dioxide laser.

2–4. Components of a laser

a. A laser has three basic components—

(1) A lasing medium.

(2) A “pumping” system (that is, supplying the energy to excite the molecules).

(3) A resonant optical cavity.

b. Lenses, mirrors, cooling systems, shutters, and other accessories may be added to the system to obtain more power, shorter pulses, or special beam shapes, but only the above three basic components are necessary for laser action.

2–5. Lasing medium

a. A medium, to be suitable for a laser, must have at least one excited energy state, which is meta-stable where electrons can be "trapped" and cannot immediately and spontaneously transition to lower energy states. Electrons may remain in these metastable states from a few microseconds (μs) to several milliseconds (ms). When the medium is exposed to the appropriate pumping energy, the excited electrons are trapped in these metastable states long enough for a "population inversion" to occur (that is, a condition where there are more electrons in this excited state than in the lower state to which these electrons decay when stimulated emission occurs).

b. Figure 2–3 shows a simplified three-level energy diagram for a laser material. This is just one of the many possible configurations of energy levels. Although laser action is possible with only two energy levels, most such actions involve four or more levels.

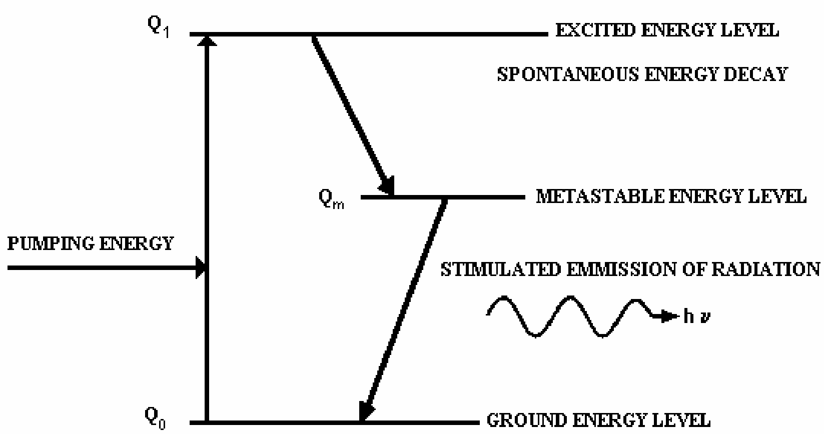
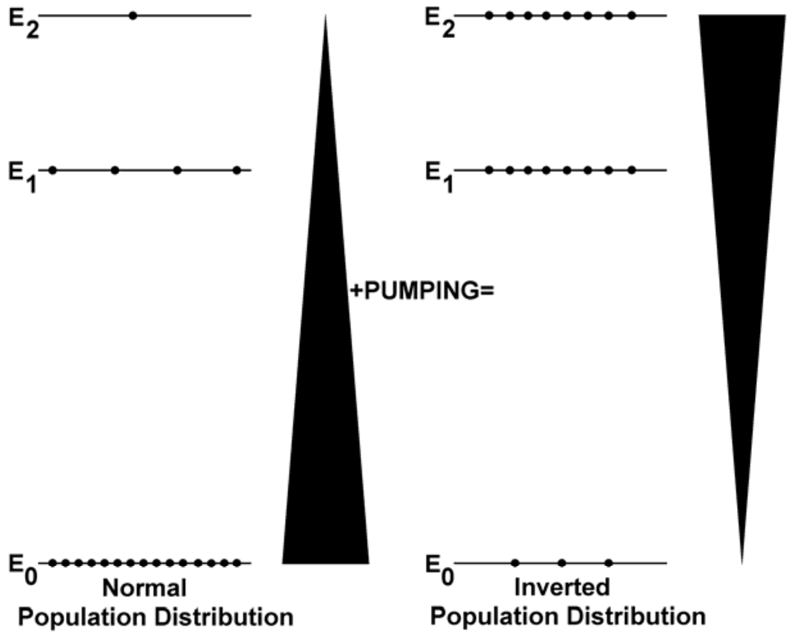


Figure 2–3. Three-level energy diagram

2–6. Pumping system

a. To raise atoms or molecules to a higher energy level, lasers employ pumping systems (figure 2–4).

b. These systems pump energy into the laser material, increasing the number of atoms or molecules in the metastable energy state. When the number of atoms or molecules in the metastable energy state exceeds those in the lower level, a population inversion exists, and laser action becomes possible. Several different pumping systems are used—



Note: E: electron energy states

Figure 2–4. Population inversion

c. These systems pump energy into the laser material, increasing the number of atoms or molecules in the metastable energy state. When the number of atoms or molecules in the metastable energy state exceeds those in the lower level, a population inversion exists, and laser action becomes possible. Several different pumping systems are used—

(1) Optical pumping uses an intense light source, such as an xenon flashtube or another laser (for example, an argon laser or diode).

(2) Electron collision pumping is accomplished by passing an electric current through the laser material or by accelerating electrons from an electron gun to impact on the laser material (for example, helium neon laser).

(3) Chemical pumping is based on energy released in the making and breaking of chemical bonds (for example, hydrogen fluoride lasers).

2–7. Optical cavity

a. A resonant optical cavity is formed by placing a mirror at each end of the laser material so that the photons of light may be reflected from one mirror to the other, passing back and forth through the laser medium (figure 2–5 - simple flat mirror system (top); rotating prism Q-switch system (middle); confocal mirror system (bottom)).

b. Lasers are constructed in this way so that the photons pass through the medium many times and are continuously amplified each time. One of the mirrors is only partially reflecting and permits a fraction of the beam energy to be transmitted out of the cavity.

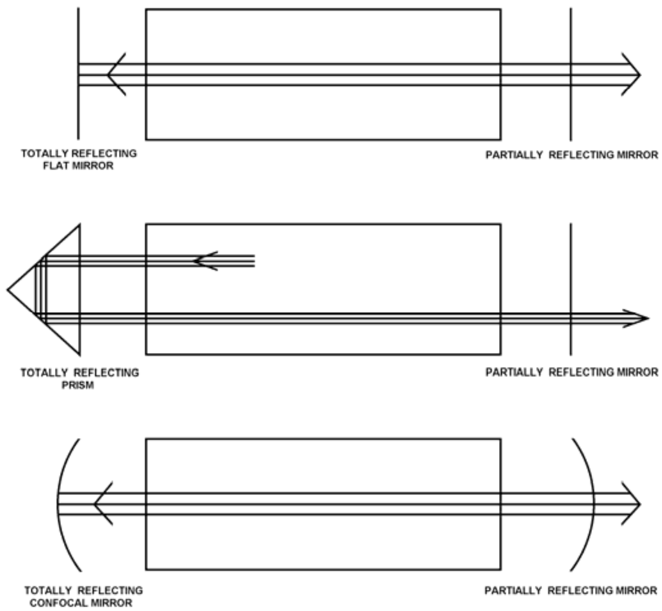


Figure 2–5. Three typical optical cavities

2–8. Types of lasers

a. Lasers are often designated by the type of laser material in the optical cavity. Lasers can produce radiation in the UV, IR and visible regions of the spectrum.

b. Table 2–1 lists several common laser wavelengths and the medium used to produce the laser.

Table 2–1
Common laser wavelengths[1]

CIE band	Wavelength nm	Medium	Typical Operation
UV-C, B, A[2]	193, 222, 248, 308, 351	Excimer	CW/Pulsed
UV-A	325	Helium-cadmium	CW
UV-A	327	Nitrogen	Repetitively pulsed
UV-A	350	Argon	CW
Visible light	441.6	Helium-Cadmium	CW
Visible light	458 ,488 ,514.5	Argon	CW
Visible light	568, 647	Krypton	CW
Visible light	532	Nd:YAG frequency-doubled	Pulsed
Visible light	511-578	Copper vapor	Repetitively pulsed
Visible light	632.8	Helium-neon	CW
Visible light	670	Diode	CW
Visible light	694.3	Ruby	Pulsed
Visible light	560-640	Rhodamine 6G dye	CW/Pulsed
IR-A[3]	700-800	Alexandrite	Repetitively pulsed
IR-A	850	GaA1As[4]	Repetitively pulsed
IR-A	905	Gallium-arsenide	Repetitively pulsed
IR-A	1060	Nd:glass	Pulsed
IR-A	1064	Nd:YAG[5]	Pulsed
IR-B[6]	1540	Erbium:YAG	Pulsed
IR-B	2900	Hydrogen fluoride	Pulsed
IR-C	3900	Deuterium fluoride	Pulsed
IR-C[7]	10,600	Carbon dioxide	CW

Notes:
[1] Source: Modified from Field Manual (FM) 8-50, table A-1
[2] Ultraviolet radiation:
(a) UV–C (100 nm–280 nm)
(b) UV–B (280 nm–315 nm)
(c) UV–A (315 nm–400 nm)
[3] IR–A (700 nm–1400 nm)
[4] GaA1As: Gallium Aluminum Arsenide
[5] Nd:YAG: Neodymium:Yittrium Aluminum Garnet
[6] IR–B (1400 nm–3 micrometer (μm))
[7] IR–C (3 μm–1000 μm)

c. Solid-state lasers employ a glass or crystalline material (figure 2–6) and commonly employ optical pumping.

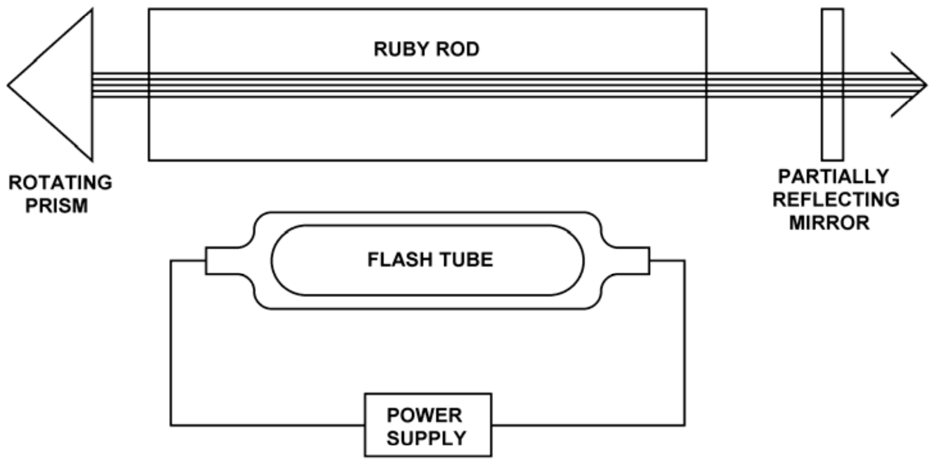


Figure 2–6. Schematic of solid-state laser with optical pumping

d. Liquid lasers employ an active material in a liquid solution or suspension, usually a dye (figure 2–7). Liquid lasers commonly employ optical pumping, although some types of liquid lasers have employed chemical-reaction pumping.

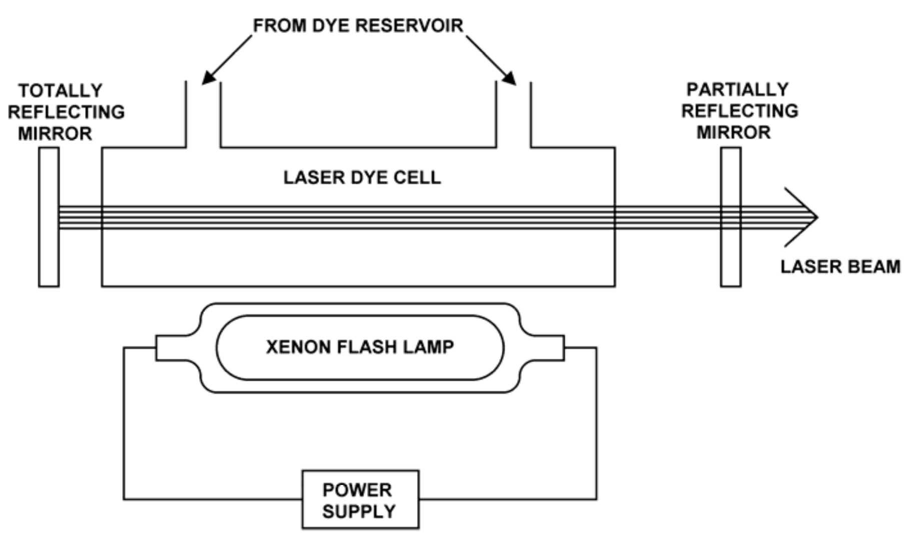


Figure 2–7. Schematic of a liquid-dye laser with optical pumping

e. Gas lasers employ a pure gas or a mixture of gases (figures 2–8 and 2–9). Figure 2–9 represents the larger type of flowing gas laser. A still larger type of gas laser, known as a gas dynamic laser (not shown), employs a combustion chamber and supersonic nozzle for population inversion. Gas lasers usually employ electron collision pumping, although some types of gas lasers have employed chemical-reaction pumping.

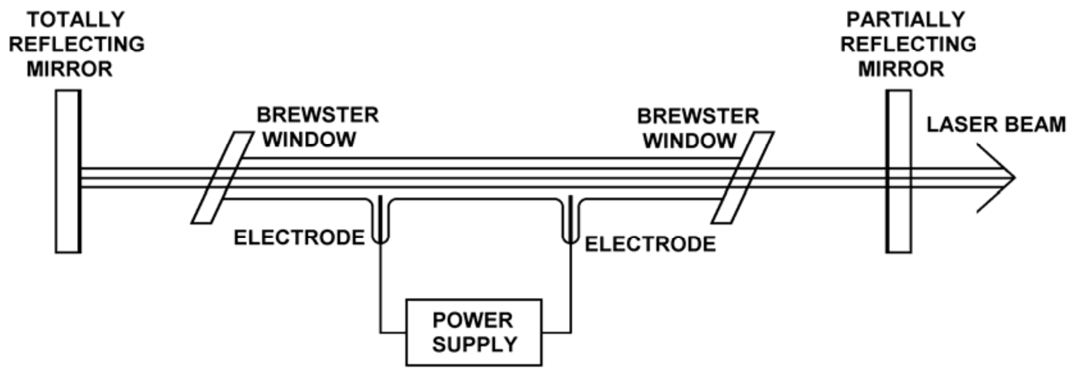
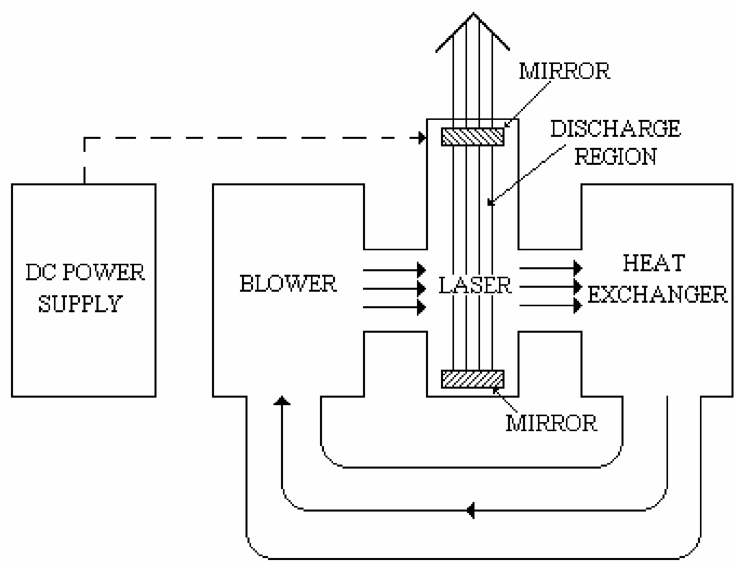


Figure 2–8. Schematic of helium-neon laser with electron collision pumping (representative of small gas lasers)



Note: DC: Direct Current

Figure 2–9. Schematic of carbon dioxide gas transport laser

f. Semiconductor lasers employ diode materials (figure 2–10). Semiconductor lasers may be optically pumped by another laser beam, electron-collision pumped by an electron beam or an applied potential difference over a diode junction resulting in an electric current.

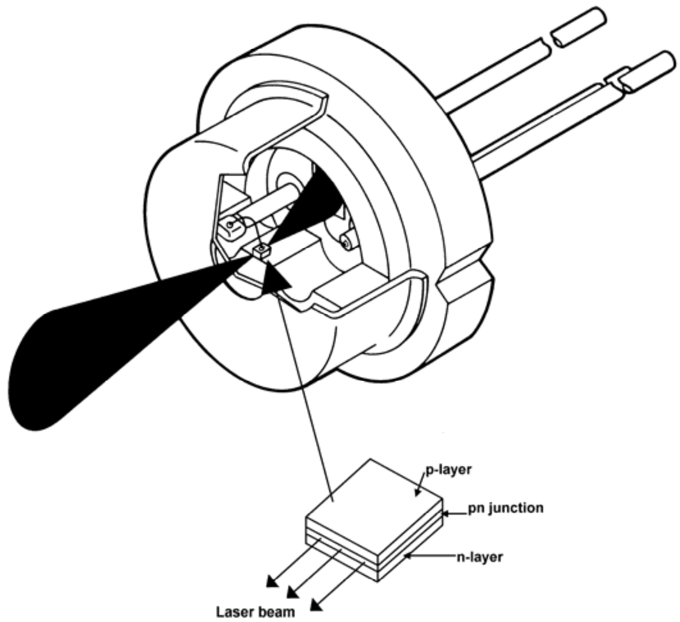


Figure 2–10. Schematic of gallium arsenide laser with direct-current (electron collision) pumping (representative of semiconductor or injection lasers)

2–9. Temporal modes of operation
The different temporal modes of operation of a laser are distinguished by the rate at which energy is delivered.

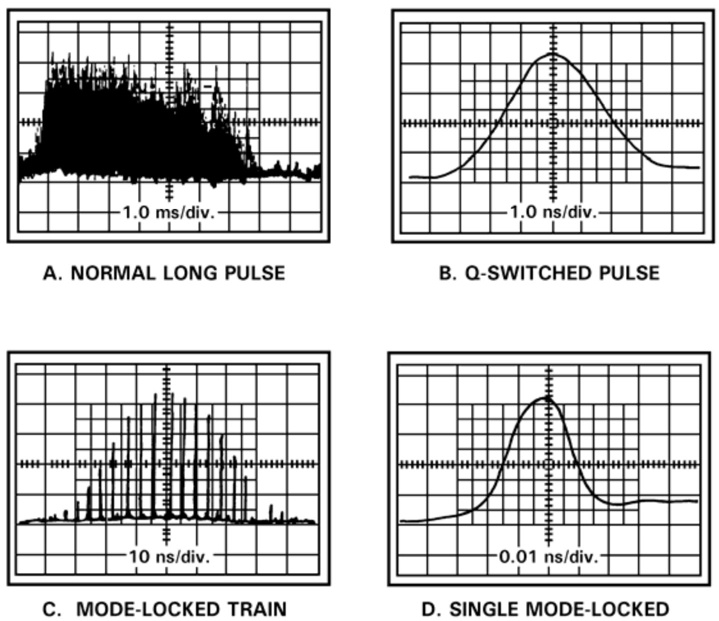
a. Some lasers are able to operate continuously. This mode of operation is called continuous wave or CW. In this temporal mode of operation, the peak power is equal to the average power output (that is, the beam power is constant with time).

b. Lasers operating in the normal-pulse mode have pulse durations of microseconds to a few milliseconds. This mode of operation is sometimes referred to as long-pulsed. The length in time of a pulse is called the pulse width.

c. The resonance quality of the optical cavity of a laser can be changed by placing special optics within the laser. These optics enable the beam to be turned on and off rapidly and normally create pulses with a duration of a few nanoseconds to a few tenths of a microsecond. This mode of operation is normally called Q-switched. The "Q" refers to the resonant quality of the optical cavity. A laser operating in the Q-switched mode delivers less energy than the same laser operating in the normal-pulse mode, but the energy is delivered in a much shorter time period. Thus, Q-switched lasers are capable of delivering very high peak powers of several megawatts or even gigawatts. Most military lasers are Q-switched with pulse durations of 1 to 30 nanoseconds (ns) and are used in target acquisition and fire control.

d. When the phases of different frequency modes are synchronized (that is, "locked together"), the different modes will interfere with one another to generate a beat effect. The result will be a laser output that is observed as regularly spaced pulsations. Lasers operating in this fashion, mode-locked, usually produce trains of pulses, each having duration of a few picoseconds to a few nanoseconds. A mode-locked laser can deliver higher peak powers than the same laser operating in the Q-switched mode.

e. Pulsed lasers can be operated to produce repetitive pulses. The pulse repetition frequency (PRF) of a laser is the number of pulses that the laser produces in a second, measured in hertz. Lasers are now available with PRFs as high as several million pulses per second. Pulse characteristics, as shown in figure 2–11, are important in laser hazard evaluations. Target designators and direct-fire simulators illuminate a target with a series of precisely spaced pulses. Training devices have laser pulse trains that contain information on the weapon type.



2–11. Pulse characteristics of several different lasers

2–10. Spatial transverse electromagnetic modes of operation

a. Certain beam geometries have transverse wave patterns, which are identified by transverse electromagnetic modes (TEM) numbers.

b. A laser operating in the TEM_{00} mode emits a beam that is circularly symmetric in shape. Figure 2–12 illustrates how several of the more common TEM modes would look in cross section.

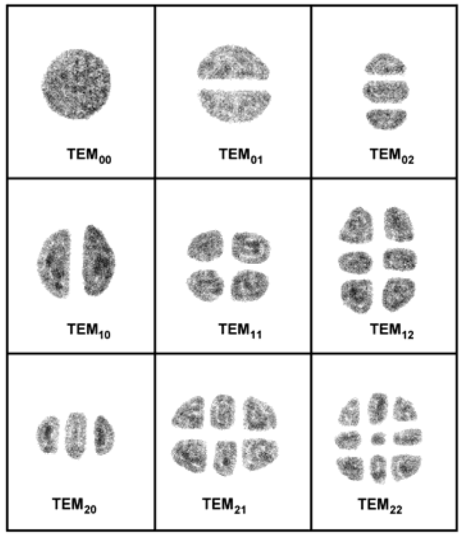


Figure 2−12. Common transverse electromagnetic modes

2-11. Beam diameter

a. The exit laser beam diameter is measured at the exit aperture of the cavity. For an approximately circular beam, the edge of the beam is defined using different criteria. Often it is defined to be the diameter of a circle where the irradiance (E) or radiant exposure falls off to 1/e or $1/e^2$ of the maximum (figure 2–13); the laser's beam diameter will contain 63 percent and 86 percent of the beam energy respectively.

b. In this bulletin, the diameter is defined at 1/e of maximum. For a circularly shaped beam, 63 percent of the laser's output energy is within the circular area defined by this beam diameter.

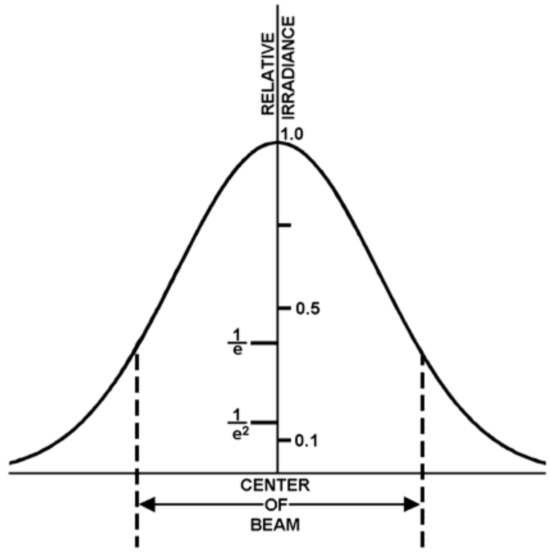


Figure 2–13. Irradiance or radiant exposure at various points in the beam cross section

2–12. Divergence

a. The beam divergence (ϕ) is the increase in beam diameter with increase in distance (that is, how fast the beam spreads out over distance). Although lasers are unable to produce perfectly collimated beams due to the wave nature of light, the divergence can be made much smaller than with any other source of optical radiation available.

b. When determining the beam diameter or beam divergence, the beam should be defined at 1/e of peak irradiance points. It is expressed as an angle and given in radians. For example, a laser beam that is 1 meter (m) in diameter at a distance of 1 kilometer (km) would have a divergence of 1 milliradian (mrad) (1/1000 of a radian). (See figure 2–14.)

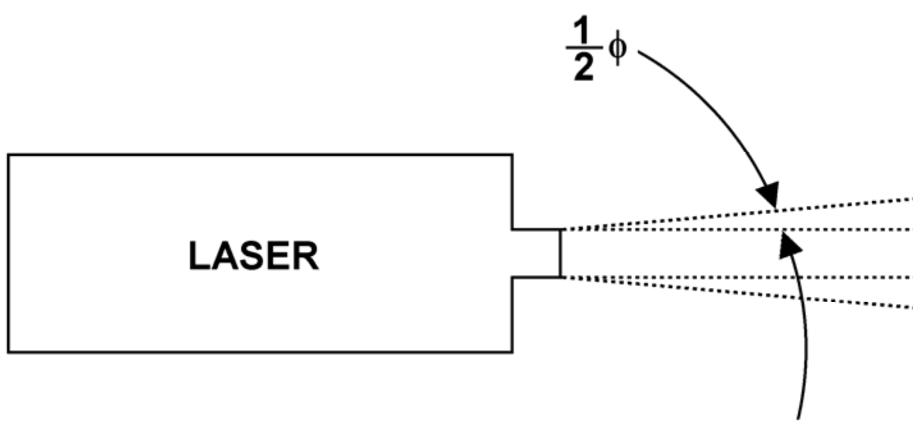


Figure 2–14. Definition of divergence angle

2–13. Hot spots

a. "Hot spots" are defined as localized areas of the beam where the beam irradiance is much greater than the average across the beam. There are several sources of hot spots: inhomogeneities in the laser cavity or areas where more energy is emitted than in other areas, imperfections in the mirrors and lenses of the laser system, and changes caused by atmospheric conditions.

b. Atmospheric inhomogeneities, or regions of different air density along the beam path, produce lenticular effects (scintillation), which are responsible for atmospheric hot spots. Fog, rain, snow, dust, smoke, or other obscuring haze absorb and/or scatter the laser beam but do not cause hot spots; in fact, such scattering reduces the effect of hot spots.

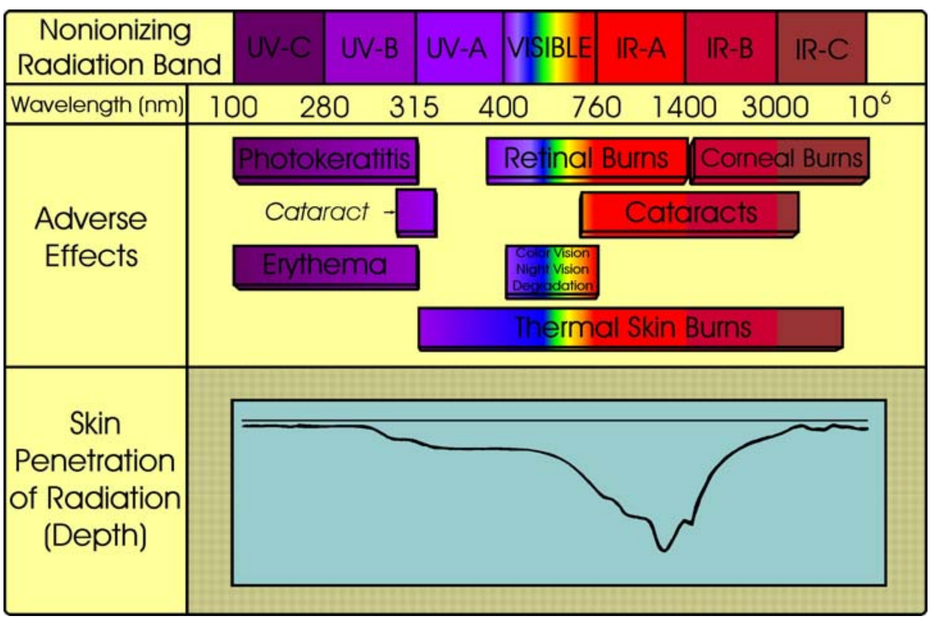
CHAPTER 3

EFFECTS OF LASER EXPOSURE

3–1. Introduction

a. Laser radiation should not be confused with ionizing radiation (such as, X and gamma rays), although very high irradiances have been known to produce ionization in air and other materials. The biological effects of laser radiation are essentially those of UV, IR, or visible radiation upon tissues. However, radiant intensities typically produced by lasers are of magnitudes that could previously be approached only by the sun, nuclear weapons, burning magnesium, or arc sources. This is one of the important properties that makes lasers potentially hazardous. A laser radiation incident upon biological tissue will be reflected, transmitted, and/or absorbed.

b. Absorption is selective. As in the case of visible light, colored material such as melanin or other pigmented tissue will absorb more energy than unpigmented tissue. Adverse effects may be caused by the heating (see figure 3–1.) Low-level adverse visual effects from visible lasers are also possible (see para 3–6).



Notes:
[1] UV–C (100 nm–280 nm)
[2] UV–B (280 nm–315 nm)
[3] UV–A (315 nm–400 nm)
[4] IR–A (700 nm–1400 nm)
[5] IR–B (1400 nm–3µm)
[6] IR–C (3 µm–1000 µm)

Figure 3–1. Adverse effects on eye and skin from nonionizing radiation

3–2. Skin

a. Adverse thermal effects resulting from exposure of the skin to radiation from 315 nm to 1 mm may vary from mild reddening (erythema or sunburn) to blistering and charring. This depends upon the exposure dose rate (power), the dose (total amount of energy) transferred, and the conduction of heat away from the absorption site.

b. Adverse photochemical skin effects resulting from exposure to actinic UV radiation (180 nm–315 nm) vary from erythema to blistering, depending upon the wavelength and total exposure dose.

3–3. Eye

a. Anatomy of the eye. Figure 3–2 shows the anatomy of the eye and those areas as they relate to the interaction with electromagnetic radiation. In almost all situations, the eye is the organ most vulnerable to injury.

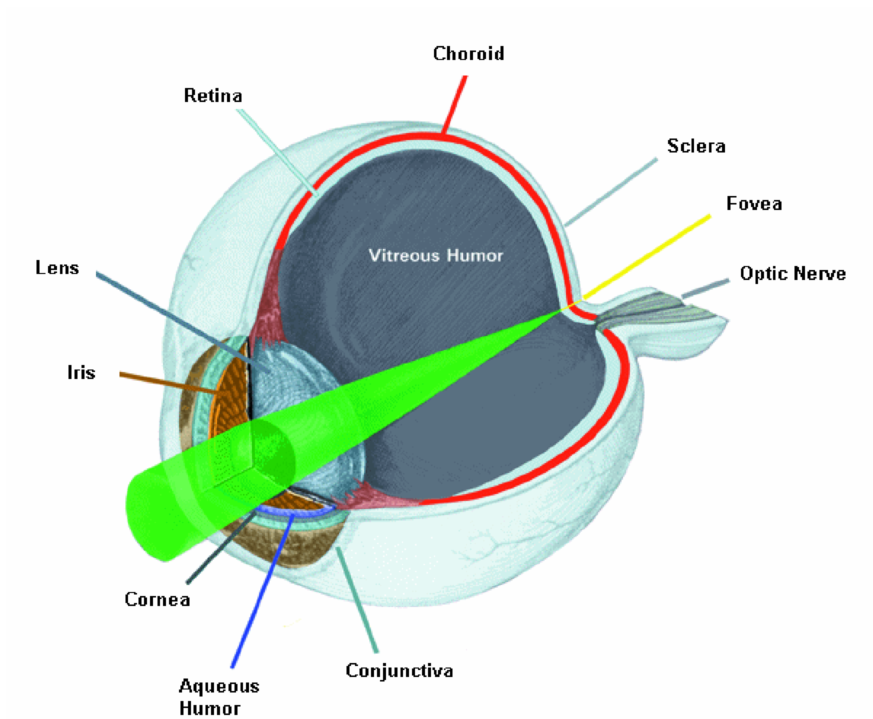


Figure 3–2. Anatomy of the eye

b. Absorption of electromagnetic radiation. Figure 3–3 provides a schematic representation of absorption of electromagnetic radiation by the eye—

(1) Most higher energy X-rays and gamma rays pass completely through the eye with relatively little absorption.

(2) Absorption of far ultraviolet (UV–B and UV–C) and far-infrared (IR–B and IR–C) radiation occurs principally at the cornea.

(3) Near ultraviolet (UV–A) radiation is primarily absorbed in the lens.

(4) Light (380 nm–780 nm) is refracted at the cornea and lens and absorbed at the retina; near infrared (IR–A) radiation is also refracted and is absorbed in the ocular media and at the retina. (See chapter 7 for a discussion on laser eye protective devices.)

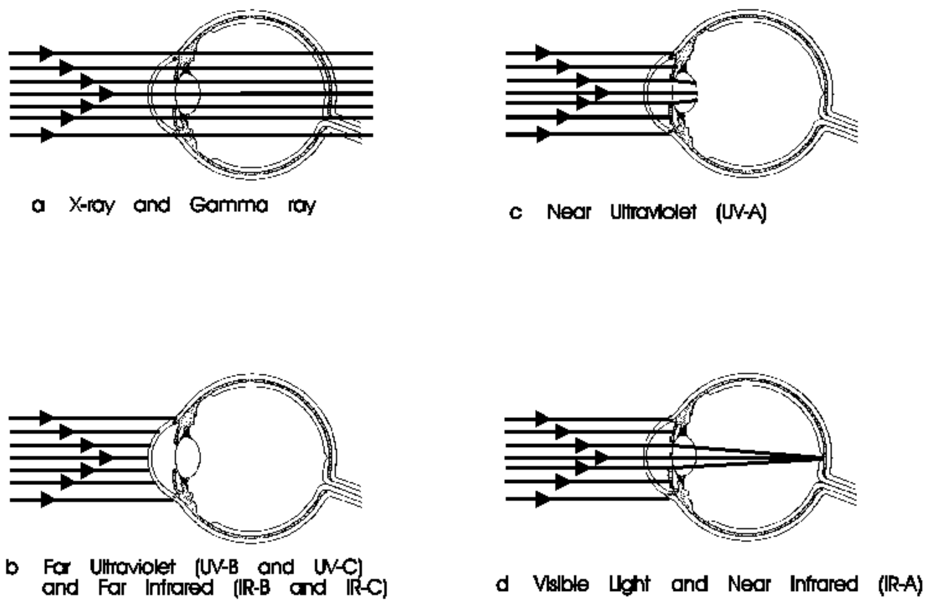


Figure 3–3. Absorption of electromagnetic radiation by the eye

c. Middle and far-infrared radiation (IR–B and IR–C)(1400 nm–1 mm) (see figure 3–3b). Absorption of far-IR radiation produces heat with its characteristic effect on the cornea and the lens of the eye. Middle-infrared radiation (1400 nm–3000 nm) penetrates deeper into skin or corneal tissue than radiation of longer wavelengths. Consequentially, optical energy from middle-infrared wavelengths delivered in short pulses is absorbed in a volume of tissue rather simply at the cornea surface. Consequentially, tissue damage occurs at radiant exposure levels much higher than far-infrared wavelengths. When multiple pulsed exposures are involved, thermal heating from the combination of pulses determines the hazard, and little difference in hazard exists for middle infrared and far infrared. For example, the 10,600 nm wavelength from the carbon dioxide laser is absorbed by the surface of the cornea and conjunctiva and may cause severe pain and destructive effects.

d. Ultraviolet radiation (180 nm–400 nm) (figures 3–3b and 3c). Actinic UV radiation, UV–B, and UV–C (180 nm–315 nm) can produce symptoms similar to those observed in arc welders. It may cause severe acute inflammation of the cornea and conjunctiva. UV–B and UV–C radiation do not reach the retina. Near UV radiation (UV–A) is absorbed principally in the lens, which causes the lens to fluoresce. Very high doses can cause corneal and lenticular opacities (clouding). Insignificant levels of UV–A reach the retina.

e. Light (380 nm–780 nm) and near-infrared (IR–A) radiation (780 nm–1400 nm) (figure 3–3d). Adverse laser effects are generally believed to be limited to the retina in this spectral region. The effect upon the retina may be a temporary reaction without residual pathological changes, or it may be more severe with permanent pathological changes resulting in a permanent scotoma (blindspot). The mildest observable reaction may be a simple reddening, but as the retinal irradiance is increased, lesions may occur, which progress in severity from edema (swelling) to hemorrhage and additional tissue reaction around the lesion. Very high radiant exposures will cause gases to form near the site of absorption, which may disrupt the retina and may alter its physical structure. Portions of the eye, other than the retina, may be selectively injured depending upon the region where the greatest absorption of the specific wavelength of the laser energy occurs and the relative sensitivity of tissue affected. Chronic low-level exposure to blue light at wavelengths between 400 nm–600 nm may produce photochemical retinal damage.

3–4. Medical surveillance

See appendix C for proper medical surveillance information and procedures for potential laser injuries.

3–5. Overexposure reporting

For any known or suspected overexposure to laser radiation, contact the installation LSO and RSO. Laser accident reporting procedures are described in AR 40–400, AR 11–9, and AR 385–40. In addition, contact the following as soon as possible after getting the accident victim immediate medical attention:

a. The USAMRD–WRAIR, Ocular Hazards Research at USAMRD–Ocular Hazards Research Branch, DNS 240–4620/4621; commercial (410) 536–4620/4621 or at http://army.brooks.af.mil/.

b. The USACHPPM LORP at DSN 584–3931; commercial (410) 436–3932 or at http://chppm-www.apgea.army.mil/laser/laser.html.

c. The USACHPPM Tri-Service Vision Conservation and Readiness Program (TVCRP) at DSN 584-2714; commercial (410) 436–2714 or at: http://chppm-www.apgea.army.mil/doem/vision.

d. For further medical surveillance information, see appendix C.

3–6. Low-level adverse visual effects

At exposure levels below the maximum permissible exposure (MPE), several adverse visual effects from visible laser exposure may occur. The degree of each visual effect is strongest at night and may not be disturbing in daylight. These visual effects are—

a. Afterimage. A reverse contrast, shadow image left in the visual field after a direct exposure to a bright light, such as a photographic flash. Afterimages may persist for several minutes, depending upon the level of adaptation of the eye (that is, the ambient lighting).

b. Flashblindness. A temporary visual interference effect that persists after the source of illumination has been removed. This is similar to the effect produced by a photographic flash and can occur at exposure levels below those that cause eye injury. In other words, flashblindness is a severe afterimage.

c. Glare. A reduction or total loss of visibility in the central field of vision, such as that produced by an intense light from oncoming headlights or from a momentary laser pointer exposure. These visual effects last only as long as the light is actually present. Visible laser light can produce glare and can interfere with vision even at exposure levels well below those that produce eye injury.

d. *Dazzle.* A temporary loss of vision or a temporary reduction in visual acuity.

e. *Startle.* Refers to an interruption of a critical task due to the unexpected appearance of a bright light, such as a laser beam.

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CHAPTER 4

LASER HAZARD CLASSIFICATION AND EVALUATION

4–1. Introduction

a. A practical means for both evaluation and control of laser radiation hazards is to first classify laser devices according to their relative hazards and then to specify controls for each classification. (See chapter 5 for indoor control measures.) Due to the unique nature of military tactical and training devices, the USACHPPM LORP will classify U.S. Army military lasers and assign NOHDs. The classification scheme presented here is similar to that used in Standards Z–136.1–2000 and Z136.6–2000. The MPEs are provided in this document for convenience. The most current ANSI Z136 standards are used when performing laser hazard classifications and evaluations. The classification scheme presented here is also similar to the Federal Laser Product Performance Standard (FLPPS) in Title 21, Code of Federal Regulations Part 1040 (21 CFR 1040) and the International Electrotechnical Commission (IEC) 60825–1, edition 1.2 (2001–2008). The federal classification already appears on commercial laser products manufactured after July 1976. Laser classifications performed using the IEC standard are now accepted by the U.S. Food and Drug Administration (FDA).

b. Three aspects of the application of a laser or laser system influence the total hazard evaluation and, thereby, influence the application of control measures—

(1) The laser or laser system's capability of injuring personnel or interfering with task performance.

(2) The environment in which the laser is used.

(3) The personnel who may use or be exposed to laser radiation.

c. The laser classification scheme is based on aspect (1). All three aspects should be considered during hazard evaluation, although aspects two and three are not easily standardized due to a laser's potential varying application. Visual interference levels are based on aspects contained in paragraphs b(1) and b(2) above. Any laser or laser system should be classified according to its accessible radiation during operation.

d. For laboratory, medical, and non-military lasers, classification conforming to the FLPPS may be used to satisfy the classification requirements of this standard; although it should be noted that in some cases differences exist. If the manufacturer has modified the laser subsequent to classification, non-military lasers may be reclassified according to ANSI Z136.1 under the supervision of the LSO. The LSO should then ascertain whether any changes in control measures are required.

e. Lasers that are used for combat, combat training, or are classified in the interest of national security may be exempted from the FLPPS (see FDA Exemption 76 EL–01 DOD (21 CFR 1010.5)). The laser manufacturer must obtain an exemption letter prior to the sale of the laser from an authorized Department of Defense (DOD) procuring agency to allow the use of the

DOD exemption for that specific product. A manufacturer violates federal law if it sells a laser system not in compliance with the FLPPS to the DOD or falsely labels a laser product as exempt without a written DOD exemption letter. Further information on this process can be found in Laser Notice No. 52 issued by the FDA. These U.S. Army lasers, under the DOD exemption, are classified by USACHPPM LORP.

4–2. Laser classification

a. Laser classifications. Lasers are assigned hazard classes from Class 1 (least hazardous) to Class 4 (most hazardous). Classification should be determined at the most hazardous position along the beam path where people may be located, but not closer than 10 centimeter (cm). Table 4–1 shows the hazard classification scheme and associated risk assessment.

Table 4−1
Laser classification and risk assessment

Class[1]	Energy	Hazards	Risk Assessment Matrix[2]
Class 1	Depends on wavelength. Example: AN/PAQ-4C, Infrared Aiming Light (830 nm) below 0.7 milliWatt (mW).	Incapable of producing damaging radiation.	Effect: Negligible (IV) Hazard Probability: Unlikely (E) Risk Assessment: **LOW**
Class 2 (visible lasers only)	Depends on wavelength. Example CW helium neon alignment lasers: Cannot exceed 1 mW.	Eye protection is normally afforded by the aversion response (0.25 seconds (s) for visible). Hazards comparable to projectors or the sun.	Effect: Moderate (III) Hazard Probability: Unlikely (E) Risk Assessment: **LOW**
Class 3 (3a (3R) and 3b)	Class 3a (Class 3R). Depending on wavelength: Between 1 and 5 times the Class 1 or Class 2 accessible emission limit (AEL) Example: Multiple Integrated Laser Engagement System (MILES) devices.	Direct and specular reflection viewing hazards. Diffuse reflection is usually not a hazard.	Effect: Moderate (III) Hazard Probability: Seldom (D)–Unlikely (E) Risk Assessment: **LOW–MEDIUM**
	Class 3b. CW and repetitively pulsed lasers: cannot exceed 0.5 Watts (W) for 0.25 s. Example: Airborne Infrared Multiputpose (AIM)-1/D, Infrared Aiming Light Pulsed lasers: Cannot exceed 0.030 Joule (C_A J/ pulse or 0.125 J within 0.25 s). Example: Army Navy/Ground Vehicular, Visible Light, Fire Control (AN/VVG)-3, M1 laser rangefinder.	Direct and specular reflection viewing hazards. Diffuse reflection is usually not a hazard.	Class 3b Effect: Critical (II)–Catastrophic (I) Hazard Probability: Frequent (A)–Unlikely (E) Risk Assessment: **LOW–EXTREMELY HIGH**

Table 4–1
Laser classification and risk assessment (continued)

Class[1]	Energy	Hazards	Risk Assessment Matrix[2]
Class 4	Average power above 0.5 W Pulsed lasers: Exceeds 0.030 C_A J/pulse or 0.125 J within 0.25 s Example: Ground/ Vehicular Laser Locator Designator (G/VLLD)	Direct and specular reflection viewing hazards. Diffuse reflection may present a hazard. May pose a fire hazard May generate plasma radiation.	Effect: Catastrophic (I) Hazard Probability: Frequent (A)–Unlikely (E) Risk Assessment: **MEDIUM–EXTREMELY HIGH**

Notes:
[1] ANSI Z136.1
[2] FM 100–14

b. Alternate laser classification currently used by International Electrotechnical Commission. Alternate classifications are currently being considered by both national and international standards setting groups and may replace conventional hazard classes. These groups consist of Classes 1, 1M, 2, 2M, 3R, 3b, and 4. The number represents the class of the laser when only unaided viewing conditions are considered, and the M designation indicates that the laser would be a higher class when the effects of magnifying optics, such as a telescope or binoculars, are used. Class 3R contains most of the lasers currently designated Class 3a. The R designation indicates reduced requirements.

c. Class 1 and Class 1M. Class 1 lasers are systems that cannot emit accessible laser radiation in excess of the applicable Class 1 accessible emission limit (AEL) within the maximum exposure duration inherent in the design or intended use of the laser. Class 1 laser devices are those not capable of emitting hazardous laser radiation under normal operating or viewing conditions. Therefore, these systems are exempt from all control measures with the exception of some embedded lasers. A laser system may be Class 1 during normal use, due to interlocks on the system's housing, but may have an embedded higher-class laser within the protective housing. In some circumstances, such as during maintenance, these lasers may require that the LSO establish control measures appropriate for the class of the embedded laser. It is necessary to consider not only if the radiant exposure or output irradiance of a laser exceeds the MPE for the unaided eye, but also whether a hazard would exist if the laser pulse energy or beam power were concentrated by optics. Under the alternate classification scheme, a laser may be safe to view by the unaided eye (Class 1) but exceed the Class 1 AEL when magnifying optics are used making the laser Class 1M. However, Class 1M lasers cannot exceed the Class 3b AEL.

d. Class 2 and Class 2M. Class 2 lasers and laser systems are limited to emitting laser radiation in the visible (400 nm–700 nm) portion of the spectrum only. CW lasers emitting radiant power that exceeds the Class 1 AEL for the maximum possible time for the intended use of the laser but not exceeding 1 mW, are Class 2. Repetitively pulsed systems that emit radiant power in excess of the Class 1 AEL for the maximum exposure time for the intended use of the laser but not exceeding the Class 1 AEL for 0.25 second (s) exposure durations, are also Class 2. Precautions must be taken to prevent continuous staring into the direct beam of a Class 2 laser;

momentary (< 0.25 s) exposure occurring in an unintentional viewing situation is not considered hazardous. Under the alternate classification scheme, Class 2M lasers pose the same ocular hazards to the unaided eye as Class 2 but are potentially hazardous when viewed with magnifying optics. However, Class 2M lasers cannot exceed the Class 3b AEL.

e. Class 3. Class 3 lasers are separated into two subclasses: Class 3a and Class 3b. Under the alternate classification scheme, Class 3a becomes Class 3R and Class 3b becomes Class 3B.

(1) Class 3a lasers have an accessible output between 1 and 5 times the Class 1 AEL for wavelengths shorter than 400 nm and longer than 700 nm. Class 3a lasers in the visible (400 nm–700 nm) portion of the spectrum must have an accessible output between 1 and 5 times the Class 2 AEL. Class 3a also has two subcategories: those that require a "Danger" label and those that only require a "Caution" label.

(a) The signal word "Danger" is placed on all warning labels for Class 3a (Class 3R) lasers that exceed the MPE for unaided viewing beyond distances of 10 cm from the laser exit aperture.

(b) Class 3a lasers that only exceed the MPE, when viewed through optics at distances > 2 m from the laser exit aperture, use the signal word "Caution" on their warning label. By the alternate classification method, these lasers are either Class 1M or Class 2M depending on the laser's wavelength.

(2) Class 3b laser devices are potentially hazardous if the unprotected eye views the direct or specularly reflected beam, but they normally do not cause hazardous diffuse reflections.

(a) Ultraviolet (180 nm–400 nm) and Infrared (1400 nm–1 mm) include all lasers that can emit accessible radiant power in excess of the Class 3a AEL for the maximum possible time for the intended use of the laser but not exceeding a 0.5 W average power for times ≥ 0.25 s or not producing a radiant energy > 0.125 Joule (J) within an exposure time of < 0.25 s.

(b) Visible (400 nm–700 nm) includes all lasers that can emit accessible radiant power in excess of the Class 3a AEL for the maximum possible time for the intended use of the laser but not exceeding a 0.5 watt (W) average power for times ≥ 0.25 s or not producing a radiant energy > 0.03 J/pulse. For this criterion, all pulses occurring within t_{min} are considered a single pulse.

(c) Near infrared (700 nm–1400 nm) includes all lasers that can emit accessible radiant power in excess of the Class 3a AEL for the maximum possible time for the intended use of the laser but not exceeding a 0.5 W average power for times ≥ 0.25 s or not producing a radiant energy > $0.03C_A$ J/pulse. For this criterion, all pulses occurring within t_{min} are considered a single pulse.

f. Class 4. Class 4 lasers emit laser radiation in excess of the Class 3b AEL. Class 4 laser devices are hazardous if the unprotected eye views the direct or specularly reflected beam. Class 4 lasers may be fire, skin, and/or diffuse reflection hazards.

4–3. Hazard evaluations

a. Only a laser safety specialist trained in laser safety and optical engineering and/or physics is suited to perform the detailed hazard evaluation calculations or the classification determinations of a laser or laser system. Examples of these calculations can be found in appendix B.

b. U.S. Army laser equipment designed for use in combat or in combat training are required to have a laser hazard evaluation study performed by the USACHPPM LORP. Acceptable fielded laser systems are listed in MIL–HDBK–828. Laser systems evaluated by the U.S. Navy or U.S. Air Force for listing in MIL–HDBK–828 are approved by the individual service Laser System

Safety Review Boards. For systems designed for use at a single installation or for lasers that have been modified, such that the hazards may have changed in type or severity, the LSO determines the laser class if it is not provided by the manufacturer.

c. In some instances, the LSO may not possess the qualifications to make these determinations; the LSO should then contact the USACHPPM LORP for technical consultation. If hazard measurements are conducted, the laser must be adjusted to produce the most hazardous exposure conditions for the intended use.

4–4. Evaluation of personnel injury hazards

a. Control measures necessary for outdoor operations rely heavily on a complete hazard evaluation of the laser system rather than just the laser hazard class. The hazards vary greatly depending on the operating conditions and the proximity of individuals to the laser and to the laser beam path.

b. Measurement of beam divergence is often required since manufacturers' specifications are usually based on performance rather than safety. For that reason, beams that produce more energy per pulse or smaller beam divergences are perceived as better systems, although the personnel hazard may be increased. A hazard evaluation should be performed on Class 3a lasers that are: intentionally designed to be pointed at personnel during training, designed for a controlled test, or designed for combat exercise (such as Multiple Integrated Laser Engagement System (MILES) devices).

c. A hazard evaluation for visual interference hazards should be performed for visible (380 nm–780 nm) lasers if they are used outdoors at night. A hazard evaluation must be performed for Class 3b and Class 4 lasers.

4–5. Determining ocular maximum permissible exposures

a. The MPE is defined as a level of laser radiation one could be exposed to without hazardous effects or adverse biological changes to the eye or skin. Exposure to levels at the MPE, although not dangerous, may be uncomfortable to view or feel upon the skin. Therefore, it is recommended to keep exposure levels as far below the MPE as possible without having a negative impact on the laser system's performance capabilities.

b. Lower exposure MPE values are necessary for visible wavelength (400 nm–700 nm) lasers when the eye is immobilized or has a large pupil such as in health care with ophthalmic instruments or in research situations. These lower MPE values are needed in order to protect against injury to the eye from visible light exposure, while the normal protective mechanisms of the eye (such as, eye movement and pupil constriction) have been prevented by drugs or other means. See appendix E for the single pulse or single exposure MPE tables and figures. Several variables must be known about a laser or laser system before an MPE can be calculated.

(1) *Wavelength.* The wavelength (λ) of the laser must be known to specify which spectral region of the MPE table is applicable. The MPEs are arranged in broad wavelength regions expressed in nanometers. For lasers that emit at more than one wavelength, the MPEs for each wavelength must be determined separately.

(2) *Exposure duration*. The length of time that an individual could be exposed to the laser light has to be known. If a laser emits a single pulse, then the exposure time is simply the pulse duration t (duration of a single pulse or exposure) at half power points. For exposures to UV (< 400 nm) or IR (> 700 nm) wavelengths, the CW exposure duration is defined as the maximum time of anticipated direct exposure (T_{max}). A T_{max} of 10 s provides a sufficient hazard condition for either incidental viewing or purposeful staring for the hazard evaluation of retinal exposures in the near IR (700 nm–1400 nm). In this case, normal eye movements provide a natural exposure limitation. In special applications, longer exposure durations may be appropriate. For CW visible (400 nm–700 nm) lasers, the exposure duration is again the maximum time of anticipated direct exposure (T_{max}). If the laser is not designed for purposeful staring into the beam, the human aversion response time, 0.25 s, may be used for visible lasers.

(3) *Extended and small sources*. For MPE calculations within the retinal hazard region (400 nm–1 400 nm), sources are either extended or small. Small sources subtend a visual angle ≤ α_{min} (1.5 mrad). A "small" (20–30 micrometer (μm)) or nearly diffraction limited retinal image results when viewing a laser from within a collimated beam. Table E–1 lists the MPEs for small sources. Extended sources (diffuse reflections or some diode lasers) are defined as sources that subtend an angle > α_{min}. The MPEs for extended sources are listed in table E–2 of appendix E. The MPEs in the wavelength range 400 nm–600 nm are based on both thermal and photochemical effects to the retina. For extended sources, both the photochemical and thermal MPEs must be computed to determine which results in a lower, more restrictive MPE. For thermal effects of extended sources, a correction factor C_E based on the apparent visual angle subtended by the source, is used to modify the small source MPEs for application to extended sources (see table E–3). Table E–2 provides the MPEs for photochemical effects as radiance or integrated radiance averaged over a cone angle, γ (see table E–5).

(4) *Repetitive exposures*. The methods for establishing the MPEs for repetitively pulsed lasers for specific spectral regions are given below.

(a) Guideline 1 - single pulse maximum permissible exposure. The exposure from any single pulse in a train of pulses shall not exceed the MPE for that pulse duration. This protects against a thermal injury caused by pulses having greater than average energy.

(b) Guideline 2 - average power maximum permissible exposure for thermal and photochemical hazards. The exposure from any group or subgroup of pulses in a train delivered in time T (total duration exposure (in seconds) of a train of pulses) shall not exceed the MPE for time T. Complex pulse trains may require the calculation of several MPEs all based on different pulse groupings. This MPE calculation usually results in a lower MPE value for lasers with a high PRF than by applying Guideline 3. This protects against a cumulative photochemical injury and also prevents a thermal injury caused by heat buildup from average power.

(c) Guideline 3 - multiple pulse maximum permissible exposure for thermal hazards. This guideline applies for thermal injury mechanisms but not photochemical effects. The single pulse MPE for this guideline is determined by t_{min}, or the duration of a pulse train when the pulses within the train are separated by $<t_{min}$ and the duration of the pulse train is longer than t_{min}. Exposure for any single pulse (or group of pulses defined as a single pulse by this guideline) shall not exceed the single pulse MPE multiplied by the multiple pulse correction factor C_p. C_p is $n^{-0.25}$ where *n* is the number of pulses or pulse groups defined as a single pulse that occur

within the exposure duration. For this guideline, all emitted pulse energy by a group of pulses that is defined as a single pulse is combined and considered the pulse energy. Since single pulses (including groups of pulses with inter-pulse spacing $<t_{min}$) lasting longer than 0.25 s are considered CW exposures, C_p does not apply for individual exposures lasting more than 0.25 s. Groups of pulses that are defined as a single pulse, and individual pulses that are separated by an exposure duration of at least t_{min} are considered as repetitive pulse exposures by these guidelines.

(d) Ultraviolet (180 nm–400 nm) repetitive exposures. Both photochemical and thermal limits exist for this spectral region, but photochemical effects are generally dominant. All 3 guidelines are used to determine the proper MPE with guidelines 1 and 2 applying to both limits and guideline 3 relating to the thermal limit only (MPE expressed as $0.56t^{0.25}$). For repeated exposures in this spectral range, the photochemical exposure dose is additive over a 24-hour period regardless of the laser's repetition rate. The applicable MPE for any 24-hour period is reduced by 2.5 times, if exposures on succeeding days in the wavelength range 280 nm–400 nm are expected to approach the MPE.

(e) Visible (400 nm–700 nm) and near infrared (700 nm–1400 nm) repetitive exposures. Dual limits exist for the region from 400 nm–600 nm. The MPE per pulse is the most restrictive (lowest) value calculated after applying guidelines 1–3. For wavelengths between 400 nm–1050 nm, the value of t_{min} is 18 µs; for 1050 nm–1400 nm, the value for t_{min} is 50 µs. In the spectral range 400 nm–1400 nm, the dividing line between guidelines 2 and 3 is the critical frequency. The critical frequency is 55 kilohertz (kHz) for wavelengths between 400 nm–1050 nm, and 20 kHz for wavelengths between 1050 nm–1400 nm, for a short unintentional exposure (0.25 to 10 s) to nanosecond (or longer) pulses. For longer exposure durations (400 nm–700 nm), guideline 2 often produces a lower limit mainly due to photochemical interaction when the product of *n* and the pulse duration exceeds 10 s.

(f) Infrared (1400 nm–1 mm) repetitive exposures. In this portion of the spectrum, only thermal effects take place. The lower MPE calculated from guidelines 2 and 3 determine the actual MPE. C_p ($n^{-1/4}$), the pulse correction factor is used unless guideline 2 results in a lower MPE. The critical frequency is much lower for these wavelengths, often just a few hertz or less. For lasers with wavelengths greater than 1500 nm but less than 1800 nm, the single pulse MPE is 1 $J \cdot cm^{-2}$ (guideline 1), the same as the CW MPE for a 10 s exposure. Therefore, t_{min} is 10 s for such lasers, and the MPE for each pulse in a train of pulses is simply the single pulse MPE divided by the number of pulses in the train. For lasers with wavelengths greater than 2600 nm, t_{min} is only 100 ns and for other infrared wavelengths t_{min} is 1 ms.

4–6. Determining skin maximum permissible exposures

a. Table E–4 lists the MPE values for skin exposure to a laser beam. For repetitively pulsed exposures, guidelines 1 and 2 apply, but guideline 3 does not apply. The MPEs for skin exposure shall not exceed the single pulse MPE or the CW MPE.

b. The MPE for exposures lasting more than 10 s for large beams (cross-sectional areas from 100 square centimeter (cm^2) to 1000 cm^2) is modified to $10{,}000/A_s$ $mW \cdot cm^{-2}$, where A_s is the area of exposed skin expressed in cm^2. The MPE is 10 $mW \cdot cm^{-2}$ for exposed skin areas exceeding 1000 cm^2. The MPE for skin exposure should not be used unless the products design or additional administrative controls prevent ocular exposure.

4–7. Use of apertures

a. The MPEs relate to biological injury thresholds only when appropriate limiting apertures are applied (see table E–5). The diameter of these apertures varies with spectral region and exposure duration.

b. The limiting aperture is the maximum circular area over which the radiant exposure and irradiance can be averaged. The area of the proper limiting aperture when multiplied by the appropriate MPE results in the Class 1 AEL. The AEL is the basis for classifying a laser.

(1) *Unaided viewing.* Table E–6 defines a set of measurement apertures used in the classification of a laser. The measurement aperture that determines laser classification for unaided viewing is the same as the limiting aperture for the eye (see table E–5). Radiant exposure or average power measurements are taken at specific distances from the laser exit aperture through a measurement aperture. The power or energy that is transmitted by the measurement aperture is called the effective power or effective energy. Classification is determined by these effective power or energy measurements not the total emitted power or energy of the laser. These measured values are compared to the calculated AEL.

(2) *Optically aided viewing.* Viewing a laser beam with optical aids (other than ordinary eyeglasses or contact lenses) may increase the risk, and therefore, the hazard classification must reflect potential use of optical aids. If the laser is intended to be used in an environment where the use of optical instruments such as binoculars or telescopes is likely, a different measurement aperture for classification (table E–6) is used. Radiant exposure or average power measurements are taken at 2 m from the laser exit port through the proper measurement aperture. These measured values are compared to the appropriate AEL. Ordinary optics usually transmit no more than 90 percent in the visible (400 nm–700 nm) and usually no more than 70 percent for near UV and IR. For wavelengths less than 302 nm and greater than 4000 nm, optical viewing devices transmit very little. Therefore, the measurement aperture is the same as the limiting aperture, since unaided viewing will be the most hazardous situation.

4–8. Nominal ocular hazard distance

a. The NOHD for direct intrabeam viewing is the distance beyond which an unprotected individual may be exposed without injury, provided he or she does not look at the laser with unfiltered magnifying optical devices. The NOHD is determined for lasers from the relevant parameters of the laser system: beam diameter, power, divergence, and pulse characteristics (see appendix B).

b. When the laser beam is directed into a backstop, such as a hill or other opaque target that has sufficient size as to encompass the required buffer areas, the effective NOHD does not extend beyond this backstop. The potential use of magnifying optics by persons within the laser beam should be considered, as it may significantly increase the NOHD.

4–9. Nominal hazard zone

The nominal hazard zone (NHZ) encompasses the entire laser beam from the laser transmitter to the laser backstop (or NOHD) including any buffer areas and any potentially hazardous specular or diffuse reflections (see figures in chapter 6).

4–10. Specular reflection nominal ocular hazard distance

a. The NOHD from a specular (mirror like) target depends on several factors. These include—

(1) The polarization of the laser.
(2) Distance from the laser to the reflector.
(3) The size of the reflector.
(4) The composition of the reflector material.
(5) The surface flatness of the material.
(6) The angle at which the direct beam strikes the reflector material.

b. When these factors are unknown, a worst-case estimate is necessary and will result in a conservative NHZ (see appendix B).

4–11. Buffer zones

The pointing accuracy and the beam divergence of the laser system determine the size of the buffer zone. A buffer angle around the target area of the laser consists of the beam divergence of the laser plus an additional angle that would preclude any reasonable chance of the beam shifting out of the target area (see figure 6–7). It is usually assigned a value 5 times the worst-case pointing inaccuracy.

CHAPTER 5

INDOOR CONTROL MEASURES

5–1. Introduction

a. The distinction between the functions of operation, maintenance, and service is important in the implementation of control measures. First, lasers and laser systems are classified on the basis of the level of laser radiation accessible during intended use (operation). Operation is detailed in the user operation instructions. Maintenance is considered as tasks specified in the maintenance instructions for assuring routine performance of the laser or laser system. This may include such frequently required tasks as cleaning and replenishing expendables. Maintenance often will not require beam access. Service functions are usually performed with far less frequency than maintenance functions and usually require access to the laser beam by those performing the service function. Service functions are delineated in the service manuals of the laser or laser systems. It should be noted that during periods of service or maintenance, control measures appropriate to the class of the embedded laser should be implemented when the beam enclosures are removed and beam access is possible. The control measures described in this section should apply when a laser or laser system is in operation.

b. Remember that the hazard classification scheme given in paragraph 4–1 relates specifically to the laser device itself and to its potential hazard based on operating characteristics. However, the environment and conditions under which the laser is used, the safety training of the people using the laser, and other environmental and personnel factors may play a role in determining the full extent of hazard control measures. The LSO/RSO should have the responsibility and authority to monitor and enforce the control and effect the knowledgeable evaluation of laser hazards. This should include such actions as establishing an NHZ, approving guidelines or standing operating procedures (SOPs), avoiding unnecessary or duplicate controls, selecting alternate controls, conducting periodic facility and equipment audits, and training. Since such situations should require informed judgments by responsible persons, major responsibility for such judgments should be assigned to a qualified person; namely, the LSO/RSO (para 1–5b(1)). Only properly trained personnel should be designated LSO/RSO and be placed in charge of Classes 3b and Class 4 laser installations or operations. The LSO/RSO may delegate specific responsibilities to the alternate LSO/RSO or other responsible person.

c. 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 sitting position. Complete enclosure of a laser beam (an enclosed laser) should be used when feasible.

d. Specific attention may need to be given to reflected beams. Figures 6–2 and 6–3 show different reflections that may occur. Viewing these reflections may also be hazardous.

e. A review of reported incidents has demonstrated that accidental eye and skin exposures to laser radiation and accidents related to the nonbeam hazards are most often associated with personnel involved with the use of laser systems under the following conditions:

(1) Unanticipated eye exposure during alignment.
(2) Misaligned optics and upwardly directed beams.
(3) Available eye protection not used.
(4) Equipment malfunctions.
(5) Improper methods of handling high voltage.
(6) Intentional exposure of unprotected personnel.
(7) Operators unfamiliar with laser equipment.
(8) Lack of protection for nonbeam hazards.
(9) Improper restoration of equipment following service.
(10) Failure to follow guidelines or SOPs.

5–2. Types of control measures

Most control measures fall into the category of common sense practices aimed at limiting the laser exposure, thus reducing the risk. Generally, controls are required for all lasers except Class 1 systems. There are three categories of control measures: engineering, administrative, and personal protective equipment (PPE). (See appendix F and appendix G.)

a. *Engineering controls*. Control measures built into the design of the laser system are preferred over other types of control measures. For further information, see MIL–STD–1425A for military lasers and 21 CFR 1040 for commercial lasers. Engineering controls include:

(1) Positioning of equipment so that the beam height is not at eye level when a person is standing or sitting.

(2) Installing door interlocks on Class 4 laser installations to preclude unprotected persons from being exposed to laser radiation in excess of the MPE.

(3) Installing warning lights on the entryways to Class 3b and Class 4 laser installations to warn personnel when the laser is operating.

(4) Installing such items as enclosures, beam stops, beam shutters, and key controls to terminate or reduce the beam output.

b. *Administrative controls*. When engineering controls are not sufficient, a combination of engineering and administrative controls should be used. Different control measures are required depending on the class of the laser, the environment of operation, and the training of personnel. Table 5-1 lists required control measures for the various hazard classes of lasers. Some examples of administrative controls are—

(1) Guidelines or SOPs.
(2) Authorization of personnel to operate laser equipment.
(3) Laser safety training and education for select personnel.
(4) Posting warning signs, and labels.
(5) Designation of LSO/RSO.
(6) Maintaining an inventory of Class 3b and Class 4 lasers.

Table 5–1
Control measures

Control Measures	Classification						
	1	1M	2	2M	3a (3R)	3b	4
Laser Controlled Area (para 5–3)	N	N	N	N	N	X–NHZ[1]	X–NHZ
Labeling (para 9–5)	X[2]	X	X	X	X	X	X
Area Posting – Warning Signs (para 5–4)	N[3]	N	N	N	N	X	X
Guidelines or SOPs (appendix D)	N	N	N	N	N	X	X
Education and Training (para 5–5)	N	N	N	N	R[4]	X	X
Authorized Personnel (para 5–6)	N	N	N	N	N	X	X
Beam Alignment Procedures (para 5–7)	N	N	N	N	N	X	X
Eye Protection (chapter 7, appendix G)	N	N	N	N	N	X	X

Notes:
[1] X–NHZ - Required within the NHZ
[2] X–Required
[3] N–No Requirement
[4] R–Recommended

c. Personal protective equipment. When engineering and administrative control measures cannot eliminate the hazards, PPE is necessary. Types of PPE include—

(1) Goggles and spectacles.

(2) Clothing and gloves.

5–3. Indoor laser installations

a. The following step-by-step procedure is recommended for evaluation of indoor Class 3b or Class 4 lasers:

(1) Determine the hazardous beam path(s).

(2) Determine the extent of hazardous specular reflections, as from lens surfaces, mirrors and beam splitters.

(3) Determine the extent of hazardous diffuse reflections.

(4) Determine nonbeam hazards (chapter 8).

b. Class 4 laser installations require specific precautions. Class 4 lasers can not only produce potential eye hazards from intrabeam viewing and from viewing specular surfaces but may also produce hazards from viewing diffuse surfaces. Class 4 lasers may also present skin and fire hazards. Safety precautions associated with Class 4 lasers generally consist of—

(1) Door interlocks to prevent personnel exposure within the NHZ.

(2) Baffles to terminate the primary and secondary beams, and to eliminate a particular line-of-sight.
(3) The use of PPE.
(4) Safety interlocks, or a combination of engineering and administrative controls, to ensure that unauthorized personnel are denied access to the NHZ.
(5) A warning light (visible through laser protective eyewear) to indicate when the laser power supply has been activated.
(6) Good room illumination in areas where laser eye protection is required.
(7) Very high-energy or high-power lasers operated by remote control firing with television monitoring if feasible. This eliminates the need for personnel to be physically present in the same room. The enclosure of the laser, any associated beams, and the target in an interlocked box is an acceptable alternative to PPE.
(8) A sufficient thickness of firebrick or other fire-resistant materials to be used as a backstop for the laser beam. A fire hazard is one hazard associated with high-power CW far-infrared lasers, such as carbon dioxide.
(9) Enclosure of the laser beam and target area to attenuate the reflections of far-infrared laser beams. Even dull metal surfaces may be highly specular at far-infrared laser wavelengths.
c. Additional controls may be required if circumstances warrant.
(1) These controls are required specifically for children or others unable to read or understand warning labels who may be exposed to potentially hazardous laser radiation.
(2) Reliability, training, experience, and responsibility of laser user(s) to adhere to proper control procedures must be taken into consideration (for example, trainees, experienced soldiers, scientists).

5–4. Warning signs

Placarding of potentially hazardous areas should be accomplished according to local guidelines or SOPs for Class 3b and Class 4 lasers. The signs shown in figures 5–1 through 5–7 are examples.

Figure 5–1. Sample warning sign for Class 3b laser

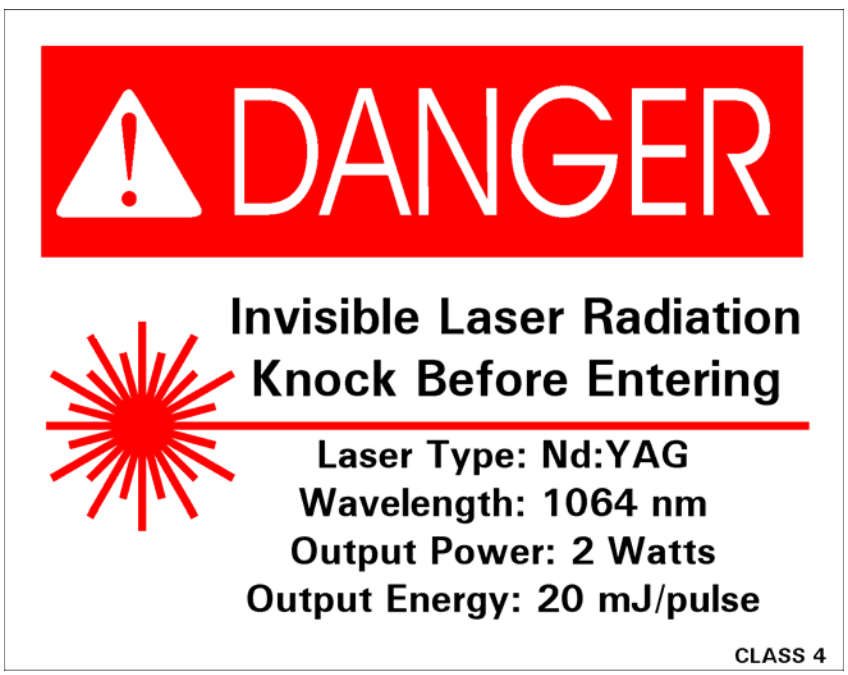

Figure 5–2. Sample warning sign for Class 4 laser

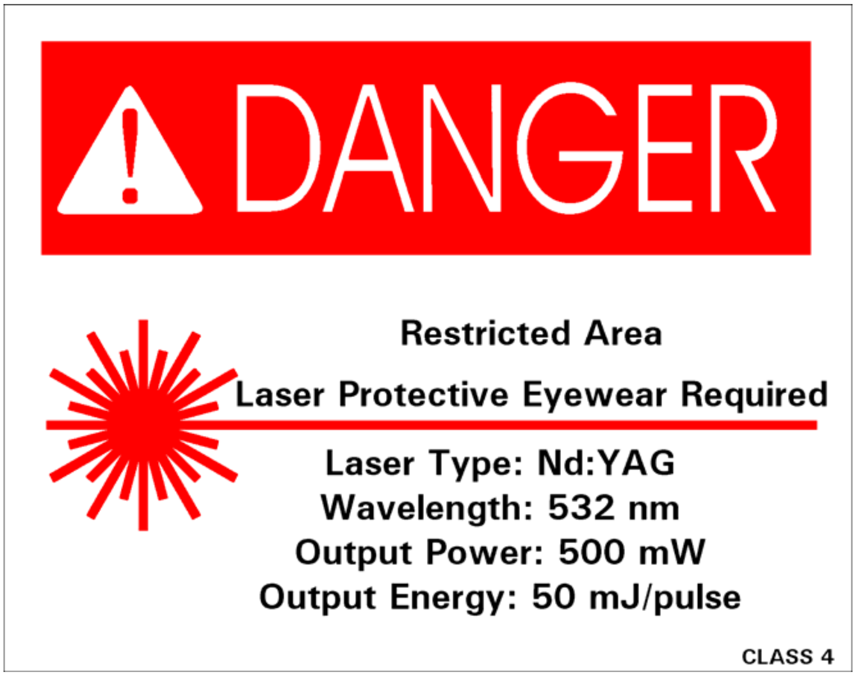

Figure 5–3. Sample warning sign for Class 4 double neodymium:yttrium aluminum garnet laser

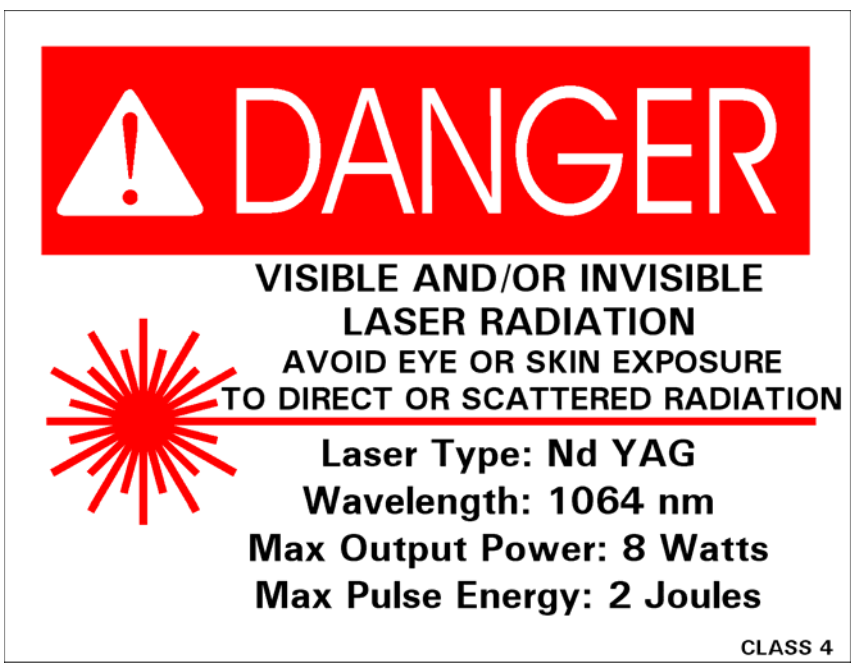

Figure 5–4. Sample warning sign for Class 4 neodymium:yttrium aluminum garnet laser

Figure 5–5. Sample warning sign for Class 4 carbon dioxide laser

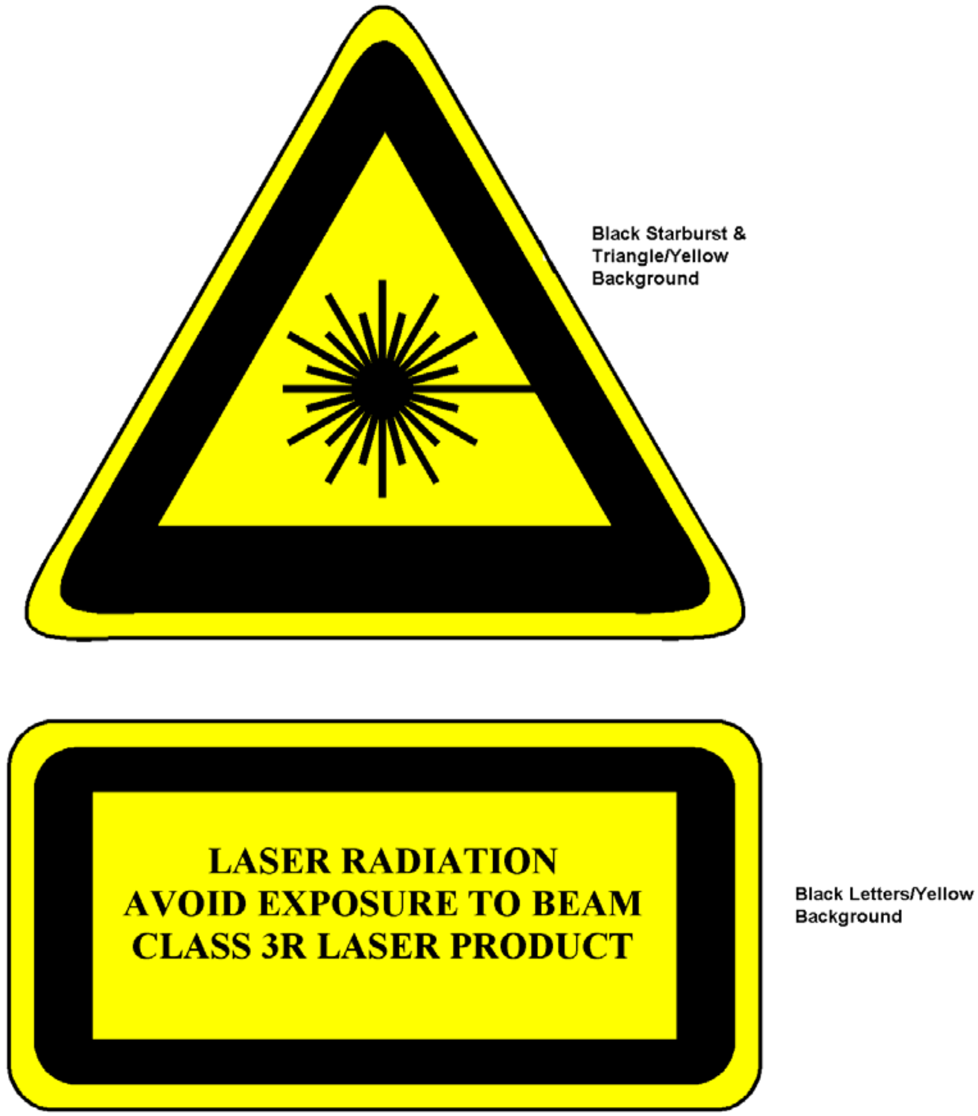

Figure 5–6. Sample International Electrotechnical Commission warning sign

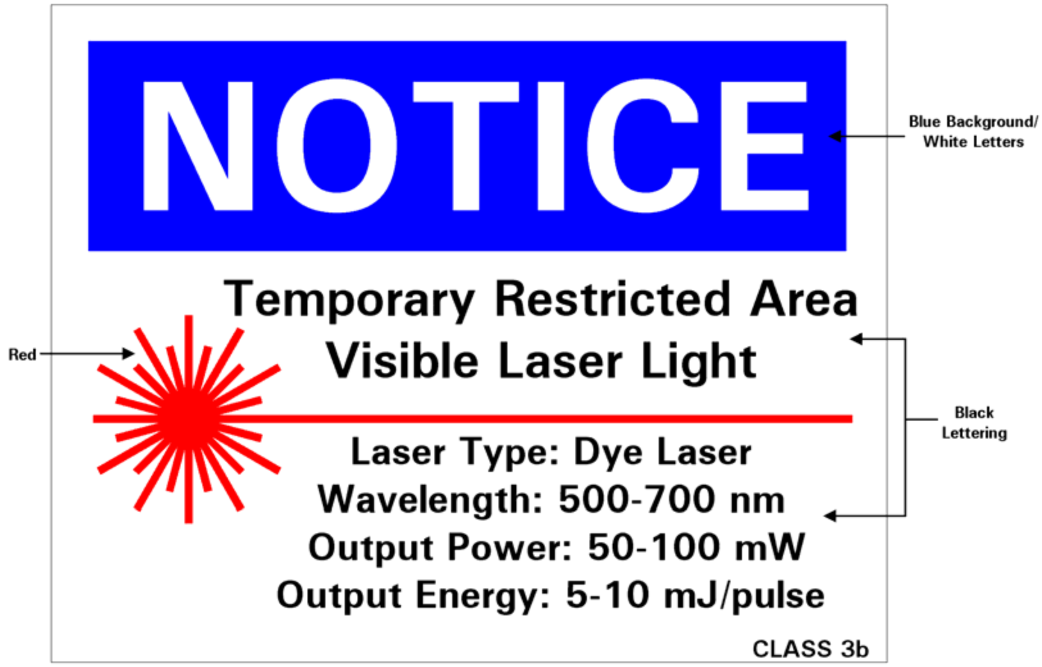

Figure 5–7. Sample warning sign for temporary laser controlled area

5–5. Education and training
Education and training will be provided to laser workers commensurate with the specific lasers that they work with and the highest class lasers to which they may be exposed. The training may be in the form of an appropriate laser safety course or may be administered through guidelines, SOPs, operator's manuals, manufacturer's literature, or other material provided by the LSO.

5–6. Authorized personnel
Operation, maintenance, and/or service on Class 3b or Class 4 lasers will be performed by authorized personnel only. Enclosed Class 3b or Class 4 lasers will be maintained or serviced by authorized personnel only if these procedures allow for potential exposure to laser radiation levels in excess of the appropriate MPE.

5–7. Beam alignment procedures
a. Beam alignment procedures have been shown as the basis for many eye overexposures. Although there are no alignment procedures for laser optical systems (for example, mirrors, prisms, and lenses) that employ Class 2 and Class 3a lasers, it is always good laser safety practice to avoid laser eye exposures that exceed the MPE.
b. A guideline or SOP that outlines a particular laser's alignment procedures must be approved by the LSO for all Class 3b and Class 4 lasers. Class 3b and Class 4 laser alignment shall be performed so that the primary beam and any specular or diffusely reflected beams do not expose the eye to laser radiation levels above the MPE. It is a good laser safety practice to use Class 1 or Class 2 lasers for alignment of Class 3b and Class 4 laser optical systems.

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CHAPTER 6

RANGE CONTROL AND OUTDOOR APPLICATIONS

6–1. Force-on-Force exercises

a. The personnel hazards associated with military exercises involving high-powered lasers (listed in appendix H, table H–1) that are intentionally pointed at soldiers by other soldiers during simulated combat are varied and specific to the particular testing environment. During such exercises, control measures such as those outlined in guideline D–8 (appendix D) that will protect soldiers as a result of injury from emitted optical radiation require careful planning to avoid injury and is beyond the scope of this section.

b. These types of exercises with Class 3B and Class 4 lasers should not be attempted without specific guidance from USACHPPM. Consult the USACHPPM LORP when planning these exercises so that appropriate laser safety precautions can be developed for that specific exercise.

c. Paragraph D–10 provides guidelines and safety practices when using lower-power training laser systems in two-sided exercises and provides examples of the controls necessary for higher-power lasers. To request the LORP's services, please contact: Commander, USACHPPM, ATTN: MCHB–TS–OLO, 5158 Blackhawk Road, Aberdeen Proving Ground, MD 21010-5403; call DSN 584–3932, commercial (410) 436–3932; or electronically at http://chppm-www.apgea.army.mil/laser/laser.html.

6–2. Background

a. The laser system, except for its inability to penetrate targets, can be treated like a direct-fire, line-of-sight weapon such as a rifle or machine gun. Thus, the hazard control precautions taken with respect to those types of weapons will be more than sufficient to provide most aspects of the safe environment required for laser use. This chapter will provide a general understanding of laser range use. For further and more detailed information, see AR 385–63 and MIL–HDBK–828A.

b. The hazard from the laser devices listed in table H–1 is generally limited to exposure of the unprotected eyes of individuals within the direct laser beam or a laser beam reflected from specular (mirror-like) surfaces. Serious eye injury with permanent impairment of vision can result to unprotected personnel exposed to the laser beam. The hazards for exposure of the skin are small compared to exposure to the eye; however, personnel should avoid direct exposure to the unprotected skin within the skin hazard distance if one exists. At normal operating distances, these lasers will not burn the skin or cause physical discomfort but can result in eye injury.

c. Essentially, the laser beam travels in a straight line so it is necessary to provide a backstop, such as a hill, behind the target during laser firing as depicted in figure 6–1. Normally, the

NOHD is the distance from the laser to the appropriate backstop. Calculated NOHDs often extend beyond 10 km, and the use of magnifying optics within the beam could extend the NOHD considerably. An official NOHD is established by USACHPPM for specialized use by installation range control officers (see table H–1).

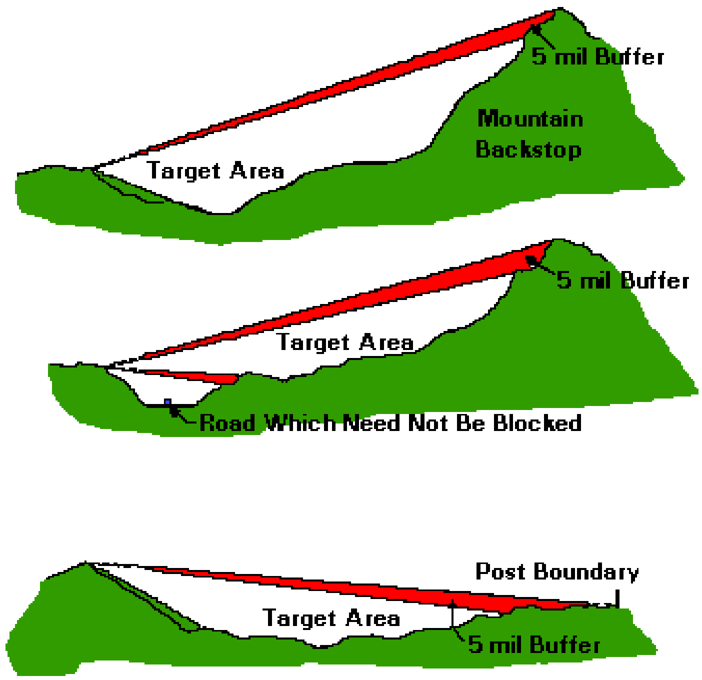


Figure 6–1. Laser range terrain profiles with backstop

d. Every object the laser beam strikes will reflect some energy back toward the laser. In most cases, this energy is a diffuse reflection and is not hazardous; however, certain flat shiny reflecting surfaces (specular) should be avoided as targets to prevent hazardous laser radiation from being reflected (see figures 6–2 and 6–3). Operators of most approved fielded military laser systems are protected against specular reflections from their laser system (see table H–1). For middle- and far-infrared laser wavelengths, specular reflections can occur from flat, smooth surfaces that appear diffuse.

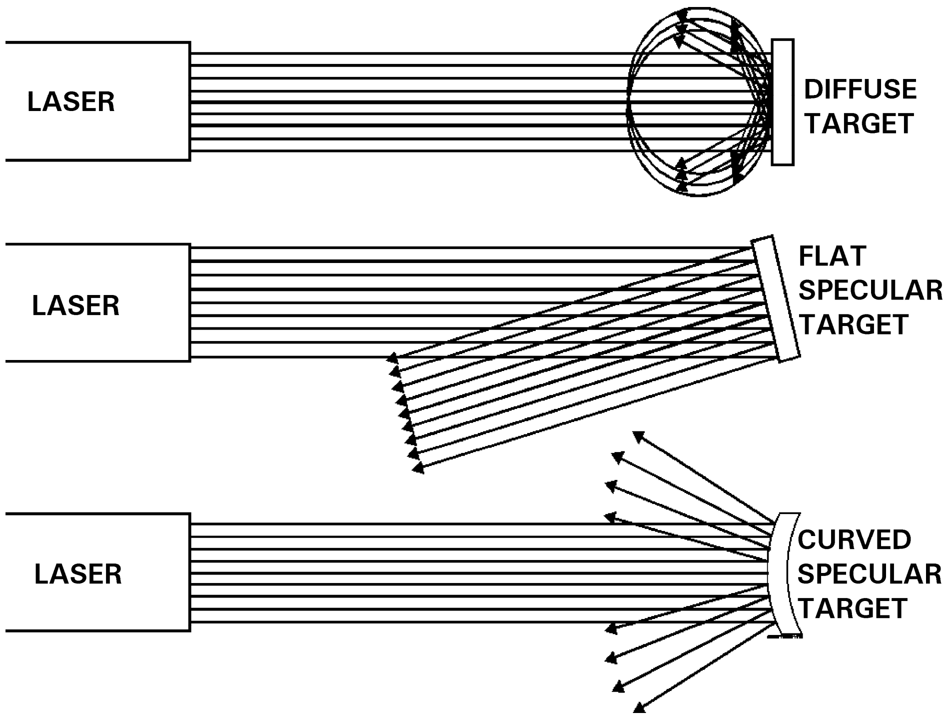


Figure 6–2. Diffuse and specular reflections

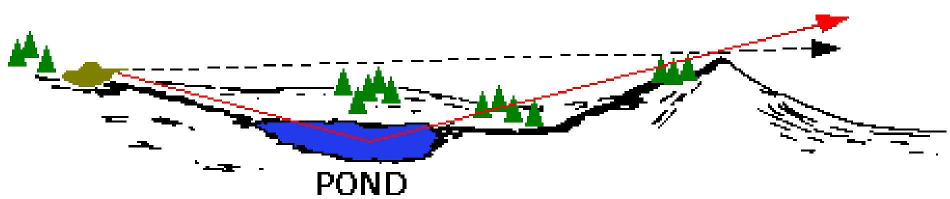


Figure 6–3. Specular reflection from water or horizontal flat glass on laser range

6–3. Laser systems

a. A list of fielded military laser systems with descriptions can be found in appendix H. Table H–1 lists several common Army fielded systems. Several systems, such as the Army/Navy/Ground, Vehicular Visible (AN/VVG)–2, are entirely phased out of the U.S. Army inventory. They may, however, be found in foreign militaries.

b. These ruby laser rangefinders (LRFs) are the most hazardous lasers to the eye at close range. These lasers not only pose a hazard from intrabeam viewing of the direct beam but also from viewing specular and diffuse reflections (see figure 6–4). The NOHDs and ODs should only be used as a general guideline. Specific questions can be addressed to the USACHPPM LORP.

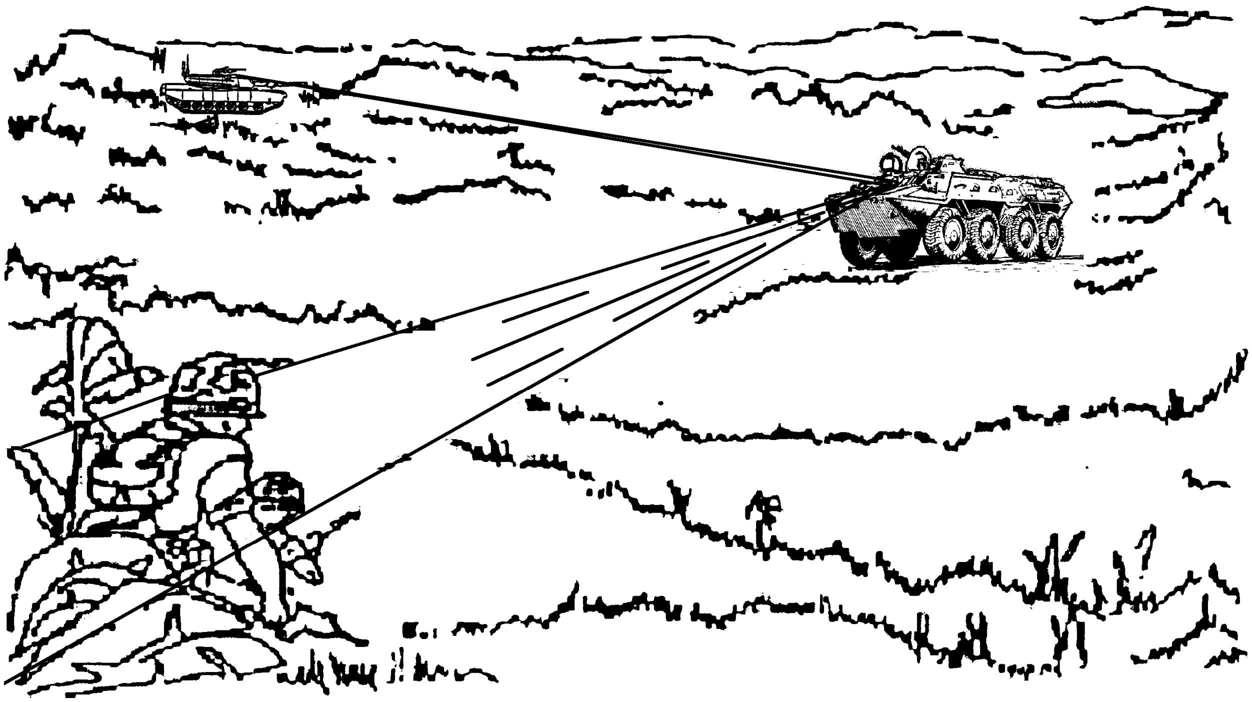


Figure 6–4. Reflected intrabeam viewing

(1) *Direct fire simulators*. Lasers used to simulate direct fire from weapons, such as MILES, are usually low-powered diode systems. These lasers are designed to be pointed at personnel during combat training. Although there is relatively little risk of eye injury from these lasers, the beams sometimes exceed the MPE within a few meters (less than 10 m for the unaided eye). All users of MILES equipment should receive laser safety training prior to the use of the equipment. Although the use of these lasers has been determined to be safe during field training, safety measures should be taken to prevent exposure to the beam during maintenance and checkout procedures. (See paragraph D–4, appendix D, for safety guidelines).

(2) *Fire control laser systems*. LRFs and laser designators (LDs) are used to determine target distance and to mark targets. These laser systems can be far more harmful to the eye than laser training devices such as the MILES laser simulators. Consequently, fire-control lasers require control measures to prevent serious eye injury. A sample list of control measures for laser operators is provided in appendix F. Sample safety guidelines can be found in Appendix D.

(3) *Laser safety summary*. Table H–1 summarizes current laser safety information pertaining to the most common fire-control laser systems. The NOHDs for unaided viewing and aided viewing, viewing the beam with NOHD-magnifying (NOHD-M) optics, such as a pair of binoculars, are also listed in table H–1. The laser beam is normally terminated within a controlled area at a distance less than the NOHD.

d. *Buffer zones*. Each buffer zone gives the minimum angular size to be added to the edges of the backstop to ensure beam termination. By ensuring that an adequate backstop is present, laser energy is prevented from leaving the controlled area. If a target approaches the skyline with no vertical buffer zone, laser operation should cease unless the airspace is controlled out to the single-pulse NOHD.

e. *Laser protective eye devices*. Table H–1 summarizes the OD requirements for intrabeam viewing with or without magnifying optics. Protective OD values for a single-pulse exposure are listed in the last column. OD is wavelength specific and may offer no protection at other wavelengths. At longer distances from the laser, the beam spreads out and becomes less harmful.

6–4. User instructions

a. In addition to instructions on particular laser devices or simulators, training material required for classroom instructors and range personnel should include—

(1) Principles of reflection and refraction of light.

(2) Personnel hazards (that is, biologic effects on eye and/or skin).

(3) Guidelines or safety SOPs.

(4) Preparation of laser ranges (for example, placement of targets and removal of specular surfaces).

b. Laser safety training should be provided for enlisted students taking advanced individual training and to officers taking basic courses as part of basic weapons systems instruction. The classroom instructors must be knowledgeable in operator and crew aspects of laser safety. Hazard data for lasers as incorporated into the field manual (FM) on the related weapon system or on the laser component should be stressed. Proper channels for obtaining professional safety and medical assistance should be addressed during training. A train-the-trainer or user-level course in laser/optical radiation hazards is available from the USACHPPM LORP.

c. Laser training filters may be available for some military laser systems. These filters reduce the output to levels that may be safe or require less control. For most military laser systems, eye protection is built into the aiming sight and protects the operator at the lasing wavelength.

6–5. Range boundaries

a. Laser ranges used for the operation of Class 3b or Class 4 lasers must have warning signs posted stating that the range is approved for laser use. These signs should be posted around the range perimeter at any access road and along areas where personnel could inadvertently enter the range.

b. Additional warning signs must be posted during actual laser operations. An example of a typical laser range warning sign is shown in figure 6–5.

Figure 6–5. Sample laser range warning sign

(1) *Nominal ocular hazard distance*. Table H–1 lists NOHDs for military lasers. Values are given for unaided and aided viewing. A 10-km NOHD could possibly be increased to 50 km when magnifying optics is used. It is usually not possible to control such long distances; therefore, a backstop is used to ensure that lines-of-sight do not exist between the laser device and potential observers beyond the target. Training filters can be used to greatly reduce the NOHD or eliminate it entirely, thus, requiring fewer safety precautions. The NOHDs, when using these filters, can also be found in table H–1.

(2) *Backstops*. Backstops shall be opaque structures or natural terrains in the controlled area that completely terminate the laser beam if it misses the target. Examples include a dense tree line, a windowless building, or a hill that completely obstructs any view beyond it and does not have a flat, mirror-like surface (see figure 6–6). The hazard distance of the laser device is the distance to the backstop; this hazard distance should be controlled. The terrain profile in the target area plays a very important role since the laser presents only a line-of-sight hazard. The optimal use of natural backstops is the obvious key to minimizing laser range control problems (see figure 6–1).

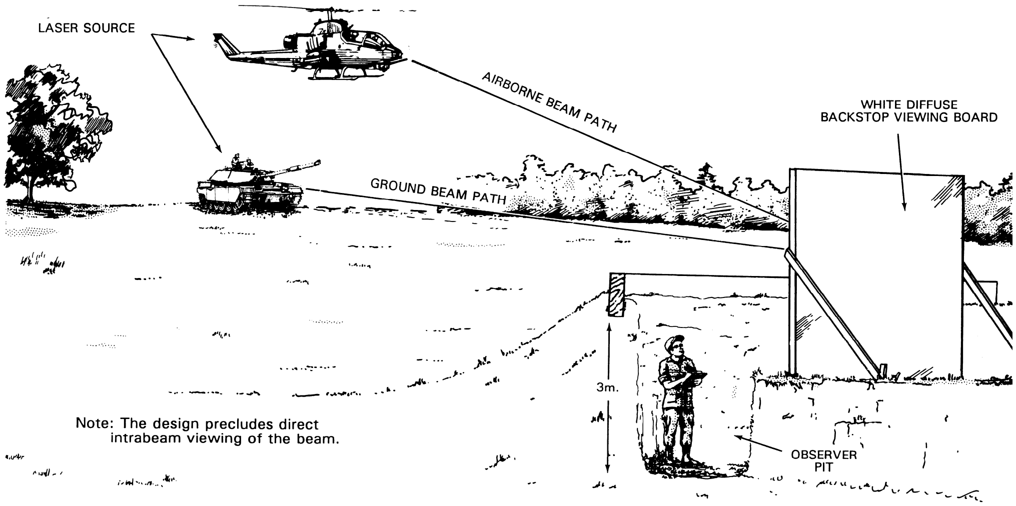
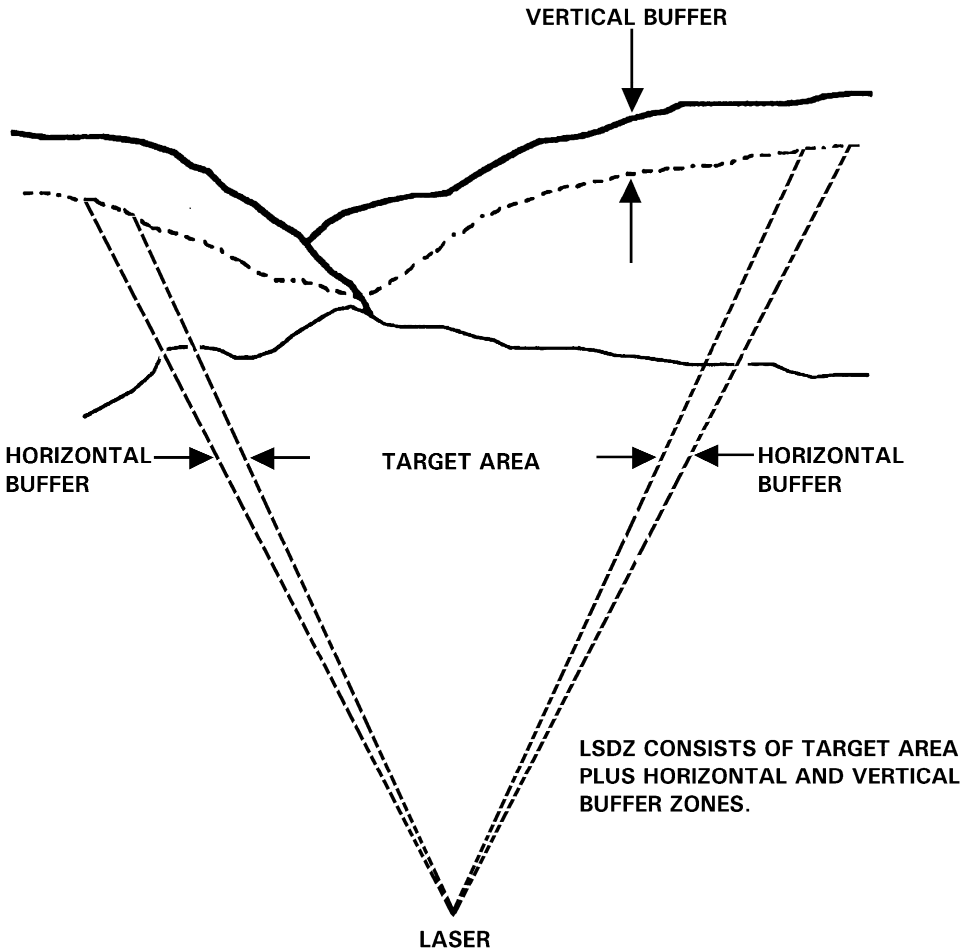


Figure 6–6. Sample range backstop

(3) *Buffer zones*. The extent of horizontal and vertical buffer zones around the target area, as viewed from the firing area, depends upon the aiming accuracy and stability of the laser device or platform. Vertical buffer zones are necessary when a line-of-sight exists to uncontrolled high ground beyond the target or when downrange air space is not controlled to the NOHD (see figure 6–7). A vertical buffer zone must be maintained below the highest point on a backstop to the target and above the lowest point on a backstop to the target area. The horizontal buffer zone covers the distance to the left of the leftmost target and to the right of the rightmost target. The laser horizontal buffer zones could be included in lateral safety or ricochet areas on ranges where the laser is used with live-fire weapons (see figure 6–8). Table H–1 lists buffer zone values for currently fielded laser systems.



Note: LSDZ: Laser Surface Danger Zone

Figure 6–7. Buffer zones

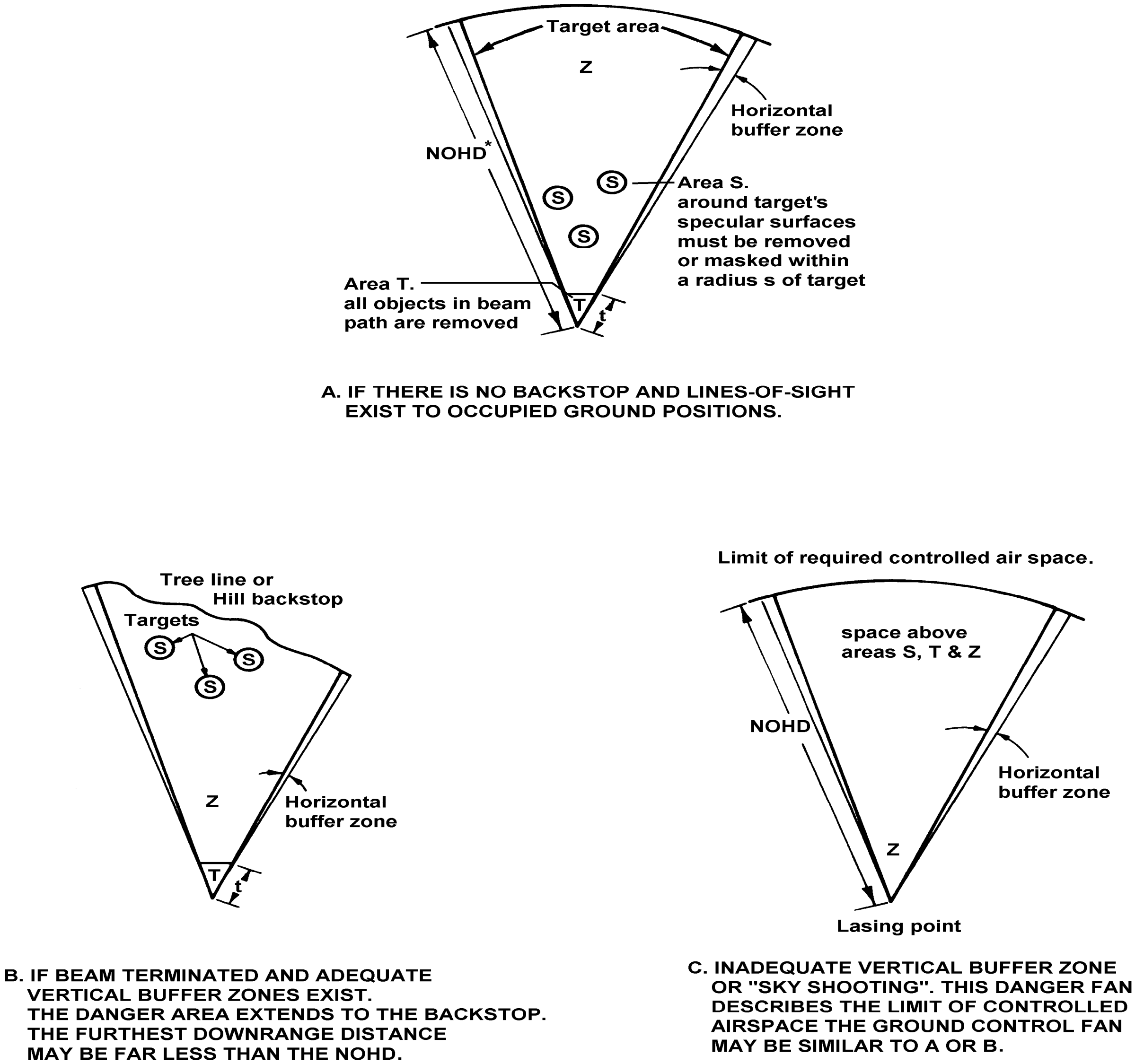


Figure 6–8. Laser safety danger zones

(4) *Specular reflections*. The entire buffered laser footprint around each target must be cleared of specular reflectors. A specular reflector is one that is so smooth one can observe an undistorted image in it. Flat, mirror-like objects are described as mirrors, flat chrome-plated metal, and panes of glass or plastic. A curved specular reflector does not create a significant risk to individuals at typical training distances from a target. However, for far-infrared wavelengths, flat surfaces that appear diffuse may also be specular reflectors.

(5) *Laser surface danger zone.* The lateral boundaries of the LSDZ include the horizontal buffer zones described above. The downrange dimensions (for example, NOHD restricted by natural terrain; see figure 6–8B) of the areas described below may differ according to the type of

device being used. Flat specular surfaces, visible from the firing line with field binoculars, should be removed within 30 m of each target. Table H–1 lists these downrange dimensions for current laser devices. Depending on the device(s) being used, the dimensions in table H–1 should be applied to the LSDZ in figure 6–8. Although the hazard of exposure to the skin is typically small, personnel should avoid direct exposure to the beam. Lasing at targets on the horizon (no vertical buffer zone) is permitted as long as air space is controlled to the NOHD for unaided viewing (see figure 6–8C). Operators should only aim at approved aerial targets. In the unusual case where there are no natural backstops available (for example, desert flats), the NOHD may extend out to extremely long ranges (for example, 25 km for a tank mounted LRF; see figure 6–8A).

6–6. Range control procedures

The underlying concept of laser range safety is to prevent intrabeam viewing by unprotected personnel. This is done by locating target areas where no line-of-sight exists between lasers and uncontrolled, potentially occupied areas and by removing specular surfaces from targets. A step-by-step procedure for evaluating a range for possible laser use is as follows:

a. Determine the extent of range boundaries (for example, NOHD and buffer zones, table H–1).

b. Evaluate the potential hazards from specular surfaces, such as those from vision blocks, flat windows, and mirrors on target vehicles. Clear a 30-m area of specular reflectors around the target vehicles. Glossy foliage, raindrops, car bumpers, and curved auto glass are not considered to be flat specular surfaces that would create ocular hazards. If target areas have no flat specular surfaces, then range control measures can be limited to the control of the beam path between the laser and backstop. When retro-reflective targets are used, a hazardous specular reflection exists from the front surface of the reflector and, in addition, a specular reflection is aimed back toward the laser.

c. Determine whether a hazardous diffuse reflection exists. Laser targets should be diffuse and not specular. Retro-reflective tape and plastic retro-reflectors (bicycle type) provide an enhanced diffuse reflection.

d. Evaluate the stability of the laser platform. Determine the extent of lateral range control and the lateral constraints that should be placed upon the beam traverse. Evaluate the need for the control of the elevation angle (for example, air space restrictions).

e. Determine if personnel participating in the exercise will be using magnifying optics. The use of magnifying daylight optical devices to observe the target during laser operation is permitted if all specular reflective surfaces have been removed from the target area. However, if these surfaces cannot be removed, either appropriate laser safety filters in the optical train of the magnifying optics or laser protective eye devices are necessary.

f. Determine the likelihood of personnel being present in the area of the laser beam (that is, ease of public access to the range).

g. Determine the proper location of roadblocks and warning signs. Local guidelines or SOPs may provide for the placement of temporary signs during operation. Signs should be according to current Occupational Safety and Health Administration (OSHA) guidelines.

h. Consider environmental conditions. Calm, smooth water, and clean ice can reflect the laser beams especially at a low angle of incidence. Consider these potential reflections when establishing target areas. Inclement weather and night operations require no additional precautions.

i. The following are considerations to be taken into account regarding personnel who may be exposed:

(1) Degree of training in laser safety of all individuals involved in the laser operation.

(2) Reliability of individuals to wear eye protection if required. Individuals within the LSDZ, such as moving targets operators, must wear laser protective eyewear with curved protective lenses during laser firing. Eyewear must be approved for the wavelength of the laser device being fired. A laser filter designed to protect against one wavelength of laser may not protect against another. See tables H–1 and H–2 for the wavelength and OD required for current fielded devices. If more than one type of laser is used, the eyewear must provide sufficient protection at all operating wavelengths. For lasers of the same wavelength, the highest required OD will be used.

(3) Expectation of individuals to be intentionally exposed to the laser light.

(4) Number and location of individuals relative to the primary beam or reflections, and likelihood of unintentional exposure.

6–7. Image intensifiers

a. Image intensifiers and thermal night sights provide some laser eye protection because there is no direct path to the eye. However, exposure to the eye is usually possible from lines-of-sight, which circumvent these devices.

b. Some devices, such as the AN/PVS–6 Laser Infrared Observation Set (see appendix H), have not been designated as laser protective eye wear because a small possibility does exist that laser energy may enter the eye through open spaces around the tube mounts in the goggles.

6–8. Countdown

A countdown is not required prior to firing in a range environment. The use of range flags, flashing lights, or temporary warning signs during lasing serves the purpose of notifying personnel when the laser is actually being used. (Range flags are also used for live-weapon firing.)

6–9. Communications

Communications must be maintained with the target area at all times. Personnel downrange in the target area shall be notified during laser operation to ensure that such personnel are wearing proper eye protection during times of actual lasing. If there is a loss of communications, lasing must be stopped until communications are re-established

6–10. Operation outside of range area

a. Maintenance shall be performed in a controlled environment according to safety guidelines or SOPs associated with the particular laser system. The beam must be contained so that personnel are not exposed.

b. Pre-fire checks that require operation of the laser can be made in a controlled area with the laser beam terminated by an opaque backstop. Pre-fire checks that do not require operation of the laser but require use of the optics can be safely made in a controlled area with the opaque dust cover or ballistic cover removed. Operating procedures must ensure power to the laser is shut down.

c. Tactical exercises can be conducted with the laser cover removed as long as the laser is inactivated.

d. If possible, the laser exit port should be covered when—

(1) Any laser device or laser-equipped vehicle is traveling on public highways, range roads, or moving from one area to another within the range and is not engaged in tactical/operations conducted in a controlled environment.

(2) The laser device or laser-equipped vehicle is stored or parked and is not engaged in tactical exercises.

6–11. Laser operations from aircraft

Guidelines are provided for operation of airborne LRFs and LDs aimed at ground targets. At most operational altitudes, airborne operations can cause ocular injury to ground personnel observing the laser source directly or viewing specular surfaces illuminated by the laser.

a. The target area should be clear of flat specular surfaces. The crew of the lasing aircraft should be instructed to visually check for possible specular items before laser operation by noting the location of standing water and the position of vehicles and buildings that may contain glass.

b. Laser protective eyewear with curved filter lenses should be made available for personnel required to be in the vicinity of the target area during laser operation. The eye protectors should provide an OD appropriate for the operation at the laser wavelength. For LRFs and LDs emitting in the visible and near-infrared regions of the spectrum and having an output energy per pulse less than 0.1 J, an OD of 6 at the laser's operating wavelength is adequate. Reduced ODs may be possible in specific instances.

c. The use of eye protection that reduces the vision of aircrew personnel should be discouraged; other hazard controls should be used instead. If a laser beam is directly illuminating the aircraft (for example, by a ground-to-air LRF), eye protection for the aircrew is necessary. Use of the laser protective visors, now available for all pilots, is encouraged when training with their lasers. These visors should not be relied on when the aircraft is the laser target since the visors were designed for combat use and not for training.

d. The flight crew should only fire the laser at designated targets.

e. All ground personnel should be instructed to assume that the laser is in operation at all times whenever the aircraft is firing on targets or is above an active range.

f. The person in charge or operator should ensure that the laser system is secured and unable to fire when the aircraft is in some location other than an authorized firing site.

g. The installation range control officer and local air traffic controllers should ensure that adequate danger zones are established and that strict control of traffic is maintained as necessary. The range control officer will—

(1) Coordinate the mission with other activities within the laser operational area and furnish all required information to control tower operators and authorized ground control stations associated with the mission.

(2) Thoroughly brief all pilots prior to any mission within the laser danger area. The briefing should include the geography of the area, access and exit routes, limits of flight pattern, radio frequencies used, and applicable local procedures. Whenever possible, each pilot assigned to a training mission should make a dry run prior to the mission to become acquainted with the prescribed course and the test area.

h. Laser operations should not be initiated unless appropriate buffer zones exist on all sides of the target within the government-controlled property area.

i. When the laser is directed into a target area that provides a positive, natural backstop (such as, a hill or valley), the vertical buffer zone may easily be kept within range boundaries. Airspace downrange of intended targets must be controlled out to the NOHD when standing water exists in the lasing area.

j. Target acquisition is prohibited within the 20-degree safety zone (figure 6–9). This safety zone, a buffer angle around the line of sight between the target and laser designator, is established to prevent the weapon system from acquiring false targets due to false signals emanating along the beam path from the designator to the target.

k. The projection of the laser beam that irradiates the ground, ground-based, sea-based, or airborne targets is elliptical. Normally, laser beams are circular, diverge equally in all directions, and produce cone-shaped beams. The size of the beam depends on the initial beam diameter, divergence (beam spread), and distance (slant range) from the laser. The size of the laser footprint is the size of the beam's projection on the target plus a buffer zone (see figures 6–7 and 6–8). For scanning systems, the size of the beam includes all potential positions of the beam. The shape of the footprint depends on the slant angle. The slant angle is determined from the distance from the laser to the target and the relative altitudes. For information on how to determine the laser footprint, see MIL–HDBK–828A.

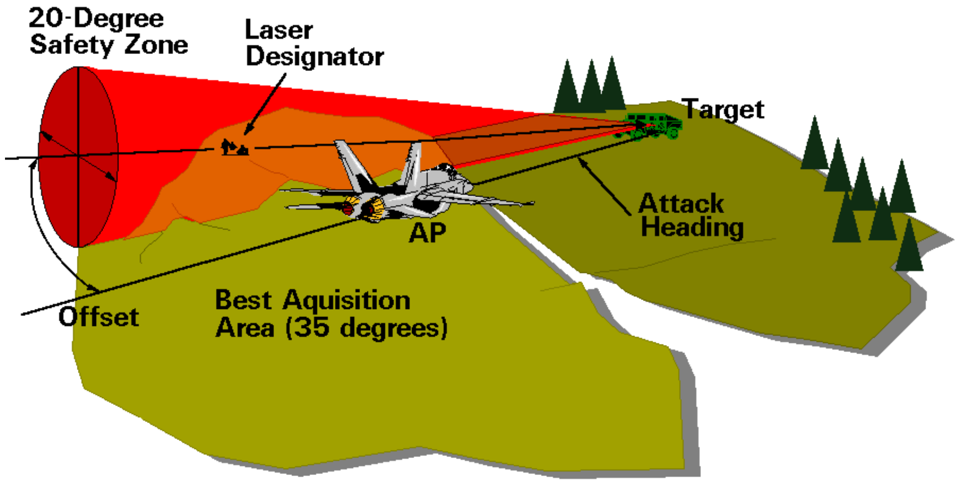


Figure 6–9. Buffer zone for a laser designator with a ground-based target

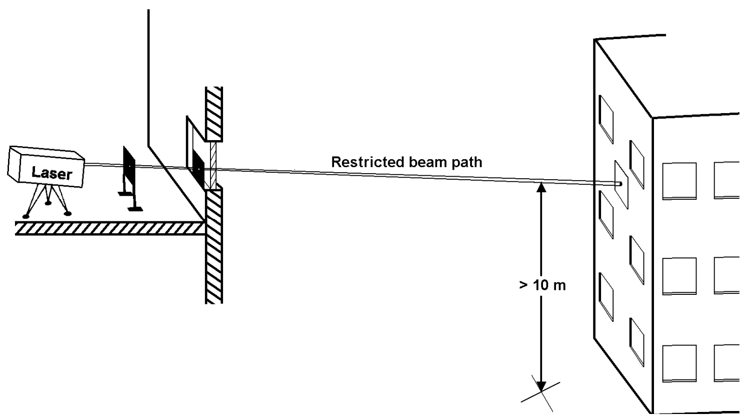
6–12. Hangar, garage, and maintenance shop procedures

a. All testing performed in shop areas will be strictly controlled with barriers and signs.

b. In shop areas, the laser beam should be contained in an enclosure, expressly designed to contain all of the laser output, when feasible.

c. The maintenance officer should clear all personnel located on site. Personnel should be restricted to those having an official interest in the test, and the number of personnel on site should not exceed those necessary to accomplish the task safely and efficiently.

d. Personnel should conduct check tests requiring operation of a laser over an extended distance (that is, 100 m–1000 m) in unoccupied areas only under strict controls. One method for controlling the beam to a tightly controlled path is by the use of apertures located at 1 m and 10 m from the laser (figure 6–10).



Note: The test range is established by limiting beam elevation and azimuth to ensure that the beam strikes a diffuse backstop; the beam path is above occupied areas.

Figure 6–10. Laser maintenance test range

6–13. Inclement weather

During periods of inclement weather, additional hazards may exist. During rain or snow, hazards from diffuse and specular reflections may exist within 1 m of the laser beam path. Water or ice on flat, non-specular surfaces could create a specular reflection when the surface is wet. Additional safety precautions may be necessary to prevent these reflections, such as covering flat optical components. Electrical hazards may also be created when rain or snow dampens electrical connections.

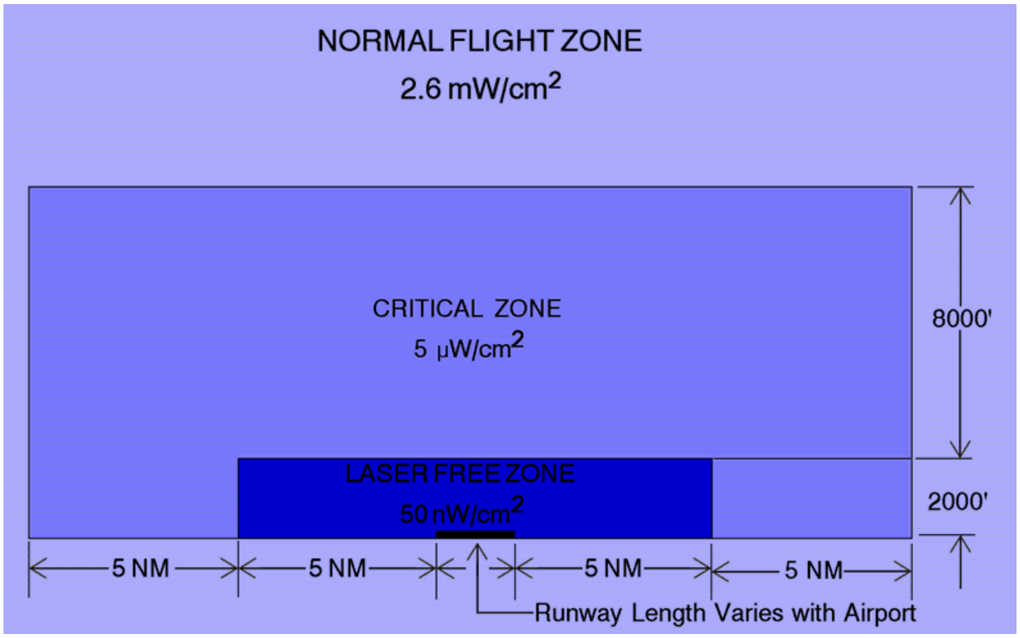
6–14. Visual interference hazards

a. General. Serious injury may result from accidents attributable to visible laser exposure that interferes with vision when personnel are performing critical tasks such as driving, flying an aircraft, or operating heavy equipment or machinery. Visual interference effects include dazzle, glare, startle, flash-blindness, or temporary visual impairment (see para 3–6). During the daytime, the laser irradiance must approach the MPE for a laser to produce hazardous visual interference effects. However, visual effects are possible with low-power lasers, such as laser pointers or laser scopes for rifles, when a person is exposed at night or in a dark environment. Laser pointers should only be used by responsible individuals and not used as toys. The misuse of laser rifle sights or laser pointers to illuminate police or other individuals may be illegal in some districts.

b. Visual interference levels. Three levels of laser visual interference are defined: sensitive, critical, and laser-free. These levels are based on visual sensitivity of the eye. The levels are provided as effective irradiance (that is, irradiance multiplied by the normalized photopic vision response function). The effective irradiance multiplied by 683 is the illuminance. In terms of effective irradiance, the sensitive level is 100 microwatt (μW)$\cdot$cm^{-2}; the critical level is 5 μW$\cdot$cm^{-2}; and the laser-free level is 50 μW$\cdot$cm^{-2}. In some instances, the MPE can be exceeded even when the visual interference level is not exceeded. When the MPE indicates more hazard, the evaluation is based on the MPE instead of the visual interference level. These levels correspond to the zones described in paragraph 6–14c.

c. Visual interference zones. Visual interference zones have been established where disruption of critical visual tasks would create safety problems. Reduced ambient illumination, dazzle, startle, or distraction by visible laser beams creates indirect hazards at levels well below those known to cause eye injury. The beam from a visible laser should not enter any visual interference zone when the irradiance is greater than the corresponding visual interference level unless adequate protective means are employed to prevent personnel exposure. Protective means should be used to protect personnel and pilots when a visual interference level could be exceeded. Aircrews may be protected either by the use of protective eyewear or by systems designed to terminate the laser beam whenever an aircraft approaches the beam path. Redundant protective systems are advisable in locations noted for heavy air traffic (see appendix H). The LSO/RSO should be aware of the location of Federal Aviation Administration (FAA)-defined zones and may designate other areas or zones that may be classified as critical or sensitive. Assignment of zones depends on the difficulty of the expected tasks and the consequences of the laser beam producing an error in the performance of those tasks. These zones are specified in the FAA Order 7400.2D and ANSI Z136.6.

(1) *Normal zone.* The normal zone encompasses all areas not included in the zones listed below. Personnel in this zone should not be exposed to levels above the MPE (see figure 6–11).



Note: nW/cm^2: nanoWatt per square centimeter

Figure 6–11. Visual interference flight zones

(2) *Sensitive zone*. The sensitive zone encompasses the area on the ground or volume of airspace where exposure to intense visible beams would interfere with critical tasks but not jeopardize safety. The local FAA office determines the sensitive zone.

(3) *Critical zone*. The critical zone encompasses the area on the ground or volume of airspace where interference with critical visual tasks, such as operating an automobile or aircraft at night, would jeopardize safety (see figures 6–11 and 6–12).

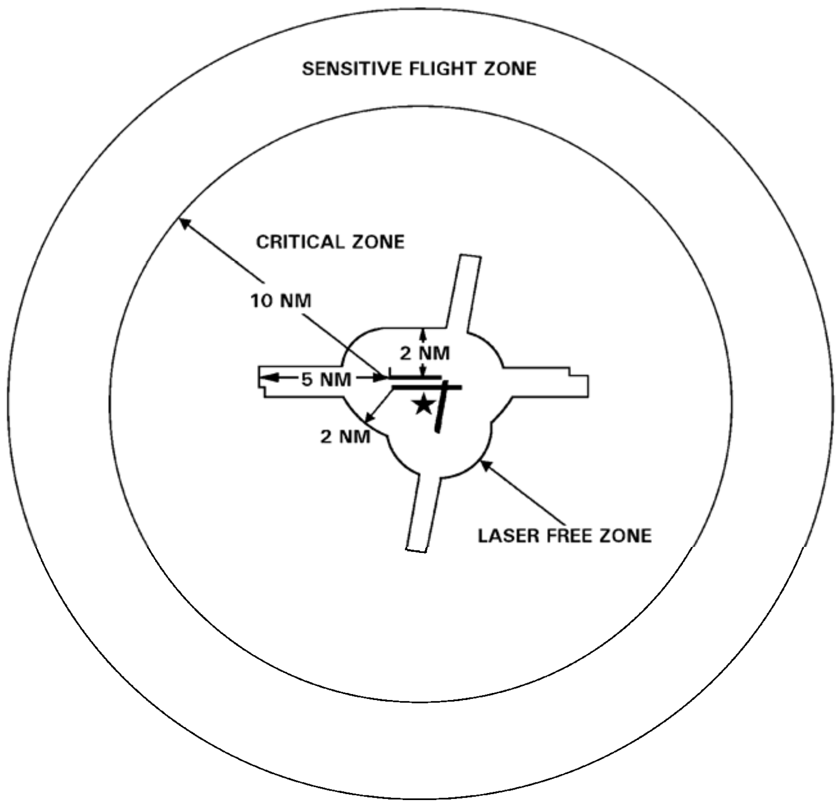
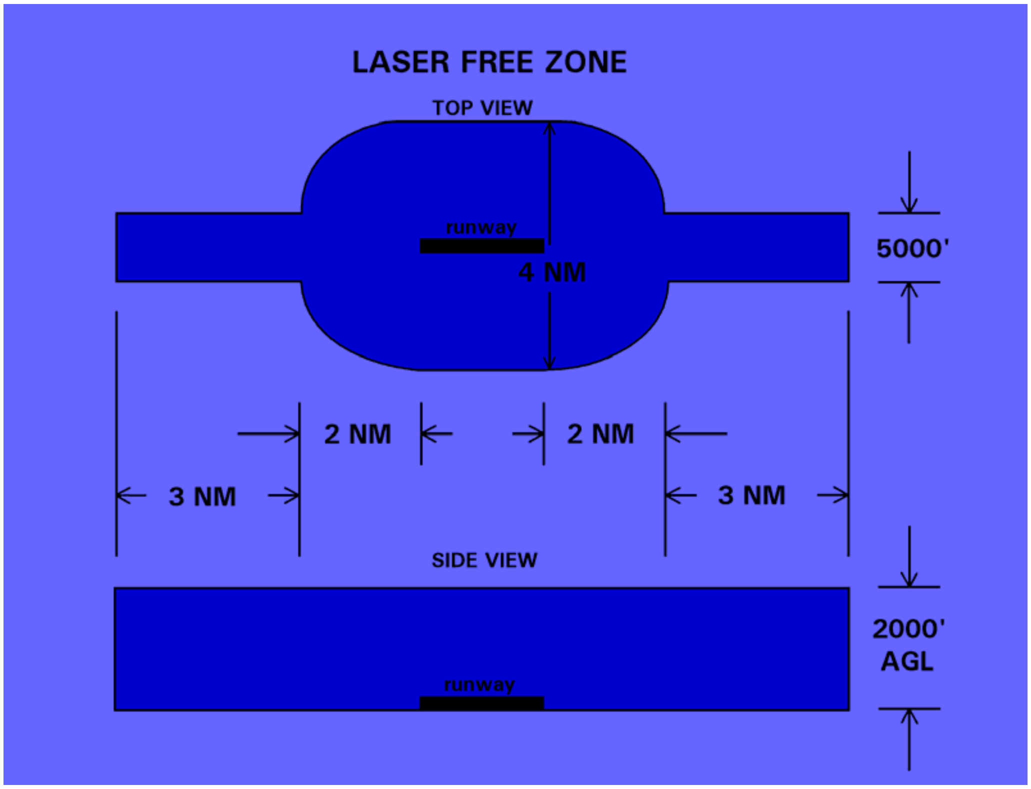


Figure 6-12. Critical and laser free zones

(4) *Laser free zone*. The laser free zone encompasses the volume of airspace immediately next to the runway. When laser beams in this zone could exceed the laser free level, redundant layers of protective mechanisms are advisable since visual interference by a laser beam in this zone would be very serious (see figures 6−11, 6−12, and 6−13).



Note: AGL: above ground level

Figure 6–13. Laser free zone

d. Visual interference duration. The degree of visual interference that is caused by a laser beam depends on the duration of the effect. In most cases, however, the duration of an unintentional encounter cannot be accurately determined since the persons are operating vehicles traveling at some speed (auto or air traffic). The duration of the visual interference may be less than 0.25 s due to flight intercept geometry or equipment design. In this document, visual interference is based on effective irradiance for exposures exceeding 0.25 s (see para 6−14b). For exposure durations less than 0.25 s, the visual interference level is based on the effective radiant exposure for 0.25 s (see table E−1).

e. Protection distances. The distances beyond which the effective irradiance is below the MPE, critical level, sensitive level, or laser free level correspond to the NOHD, critical distance, sensitive distance, or laser-free distance. The same formula for computing NOHDs may be used to calculate these other distances by substituting the visual interference levels for the MPE (see appendix B). Appropriate protective mechanisms should be employed if the laser beam intercepts a visual interference zone within the corresponding protection distance.

CHAPTER 7

LASER EYE PROTECTIVE DEVICES

7–1. Background

a. The need for laser eye protective devices has been demonstrated for all regions of the optical spectrum. Laser eye protective devices should only be used when engineering and administrative controls do not adequately control the hazard. It has been known since the early 1960s that visible and near-infrared laser wavelengths (400 nm–1400 nm) present a unique hazard to the retina of the eye due to the focusing ability of the cornea and lens. In this retinal hazard region, the eye is about 100,000 times more vulnerable to injury than the skin. In spectral regions outside of the retinal hazard region, the eye and skin are almost equally vulnerable to injury.

b. In 1962, Dr. Harold Straub of the U.S. Army Harry Diamond Laboratory, developed the first laser eye protector by installing a two- by four-inch, blue-green glass (Schott-type BG–18), filter plate into a standard acetylene welding goggle frame. Today, laser protective eyewear is available from several commercial sources in several designs; spectacles cover all types with opaque side shields and cover all types with somewhat transparent side shields (figure 7–1). Technical information on laser protective devices is available from USACHPPM LORP website at: http://chppm-www.apgea.army.mil/laser/laser.html.

c. Several factors should be considered in determining whether eyewear is necessary and, if so, selecting the proper eyewear for a specific situation. These factors include the wavelength(s) the eyewear is designed to protect against, the required OD, the visual transmittance of the eyewear, and the task being performed.

d. A note on terminology is now appropriate. Laser protective eyewear or laser eye protectors refer to goggles, spectacles, or visors worn by the individual. Laser eye protective devices is a general term applicable to eye protectors; laser protective filters placed in (or clipped onto) optical sights; or laser protective filter windows, screens, curtains, or barriers.

Figure 7–1. Commercially available laser eye protectors

7–2. Operational requirements for laser protective eyewear

a. In general, laser protective eyewear should be selected on the basis of protecting the eye against the maximum exposure anticipated while still allowing the greatest amount of light to enter the eye for the purpose of seeing. Protective eyewear must not be considered the most desirable method of providing safety. Using one or more engineering controls (that is, door interlocks, optical pathway enclosure, and design of the laser system to emit Class 1 levels only) is a more reliable safeguard for total protection. Laser protective eyewear may create an additional hazard from reduced visibility. In addition, the user may simply forget to wear them. The determination to employ laser protective eyewear should be made only after careful consideration of the alternatives and the additional problems presented by their usage. When it is not possible to use alternative controls, laser protective eyewear must be provided.

b. Laser eye protective visors may be available to fit some of the existing helmets used by aviators. To check for the availability of these visors, go to the USACHPPM LORP website: http://chppm-www.apgea.army.mil/laser/laser.html. Commercially available laser eye protectors are normally not recommended for flight crews. The added hazards resulting from loss of peripheral vision, reduced visual transmission, and degraded color contrast from most types of goggles, may outweigh the protection afforded by such eye protectors. However, during a Force-on-Force exercise or if a hazardous specular reflection is likely to be directed toward the aircraft, then aviators are required to wear high-visibility laser eye protectors. Side shields are required for the aircrew when the aircraft is a target for a laser test.

c. At present, armored vehicle crews during training exercises are not required to wear personal eye protection. If an armored vehicle is the target in laser tests or exercises, all exposed personnel in the target area are required to wear laser eye protectors. Currently, all M2 Bradley Fighting Vehicles manufactured after February 1991 have laser protective filters in all optics. The M1 tanks manufactured after August 1988 have laser protective filters built into all optics for protection against the Neodymium:Yittrium Aluminum Garnet (Nd:YAG) laser wavelength.

d. In test and training activities, eye protection with curved surfaces is required for personnel downrange within the laser beam target area and for other personnel within the NHZ if the target area cannot be cleared of specularly reflective surfaces. However, the more desirable hazard control procedure of removing specular targets from range target areas eliminates the requirement for eye protection for all but the personnel within the target area. Potentially hazardous specular reflections can exist to significant distances from flat-lens surfaces. Hence, the curved filters are far more desirable than flat-lens filters.

e. For indoor shop or laboratory environments, eye protection may be required for Class 3b or Class 4 lasers. Class 4 lasers that are diffuse reflection hazards require laser eye protection. During alignment procedures for Class 3b lasers, or Class 4 lasers that are not diffuse hazards, eye protection is required if uncontrolled specular reflections are possible. Eye protection is normally not required for Class 1, Class 2, or Class 3a lasers.

f. Army laser protective eyewear is currently being provided by Special protective eyewear, cylindrical system (SPECS); Ballistic and laser protective spectacles (BLPS); Sound protective helmet, 4th version (SPH–4) aviator laser visors; Head Gear Unit, 56th version, Pilot (or HGU–56P) Apache laser visor and laser glasses; M17 and M40 laser/ballistic protective gas mask outserts; and Sun, wind, and dust goggles (SWDG) with ballistic/laser lenses. Some of these products are still under development and not yet available through National Stock Numbers (NSN). These systems are not to be used in Force-on-Force training, research and development laboratories, testing facilities, or maintenance shops. If there are any concerns, consult with the USACHPPM LORP before using these eye protectors on training ranges.

g. Recommendations for operational hazard controls and eye protection requirements for specific Army laser systems are given in table G–1.

h. The Military Eye Protection System program is under development to replace the BLPS, SPECS, and SWDG. The concept is to provide more protection with better visibility.

7–3. Other laser protective devices

a. Built-in laser eye protective filters. Questions concerning specific ODs or protective parameters of a laser protective device should be referred to the program manager of that system. Table H–1 lists systems with built-in eye protective filters—

(1) *M22, M24, and M25 binoculars*. Users of these devices are protected against all U.S. military LRFs, LDs, and some other types of lasers.

(2) *Vision blocks*. M1 tanks have protection against the same type of laser used in the M1. Bradley vehicles may also have protection against the same type of laser used in the Bradley.

(3) *Sighting optics*. Day-magnifying optics used to point LRFs and LDs have laser protection against the same type of laser.

b. Screens, barriers, and curtains. These types of laser protective devices are used in industrial laser material processing and some laboratory and medical environments to control the laser exposure.

c. Night vision devices. These devices provide multi-wavelength protection because soldiers do not view the battlefield directly. Exposure to lasers may produce temporary or permanent damage to the devices. Night vision devices are not recommended for use as laser eye protective devices because they do not provide adequate side protection. For specific information, contact the program manager for that system.

d. Dynamic laser eye protective devices. A program has been funded by DOD to develop devices that protect against a variety of visible and near-infrared laser wavelengths simultaneously and are triggered upon exposure to the laser. They are extremely difficult to manufacture and rely on technologies that dynamically limit laser transmissions. These devices are not yet available.

7–4. Laser eye protective device parameters

a. Technical factors. The technical factors that must be considered before purchasing laser safety eyewear are—

(1) Wavelength.
(2) OD with and/or without magnifying optics.
(3) Laser power or energy.
(4) Visible transmission of eyewear.
(5) Laser filter damage threshold.

b. Other factors. Other factors that must be considered before purchasing laser safety eyewear are—

(1) Field of view provided by the design.
(2) Flatness of laser eye protective filter.
(3) Side shield requirements.
(4) Availability of prescription lenses or sufficient goggle frame size to permit wearing spectacles inside the goggle.
(5) Comfort of goggle design.
(6) Ventilation ports to prevent fogging.
(7) Effect upon color vision.
(8) Impact resistance.

c. Wavelength. Laser eye protective devices are highly wavelength dependent. Eye protection that provides attenuation at one laser wavelength may provide no protection at other wavelengths. For instance, a doubled Nd:YAG laser may emit two wavelengths: 532 nm and

1064 nm. If you provide protection only at the 532 nm wavelength, relatively little protection may be provided at the 1064 nm wavelength.

d. Optical density. OD is a parameter for specifying the attenuation afforded by a transmitting medium. Since laser beam irradiances may be a factor of a thousand or a million above safe exposure levels, percent transmission notation can be tedious.

(1) For instance, goggles with a transmission of 0.000001 percent can be described as having an OD of 8.0. OD is a logarithmic expression and is described by the following:

$$OD = \log_{10} (M_i/M_t) \qquad (1)$$

Where: M_i is the power of the incident beam and M_t is the power of the transmitted beam.

(2) Thus, a filter that attenuates a beam by a factor of 1,000 or 10^3 has an OD of 3, and one that attenuates a beam by 1,000,000 or 10^6 has an OD of 6. The OD of two highly absorbing filters stacked together is essentially the sum of two individual ODs. Calculating the required OD (OD_{req}) for a particular laser device requires knowledge of the output power or energy. For commercially available lasers, the OD may already be calculated. For military lasers, the USACHPPM LORP calculates the OD for these lasers. When optical aids are not used, the following relationship may be used when radiant exposure (H) and irradiance (E) are averaged over the limiting aperture for classification:

$$OD_{req} = \log_{10} (E \text{ or } H)/MPE \qquad (2)$$

Where: the radiant exposure (E) or irradiance (H) is divided by the MPE.

(3) When the entire beam could enter a person's eye, with or without optical aids, the following relationship is used:

$$OD_{req} = \log_{10} [\Phi_0 \text{ or } Q_0/AEL] \qquad (3)$$

Where: AEL is the accessible emission limit (that is, the MPE multiplied by the area of the limiting aperture) and Φ_0 and Q_0 are the radiant power or energy, respectively.

e. Visible transmittance of eyewear. Since the purpose of laser eye protectors is to filter out the laser wavelengths while transmitting as much of the visible light as possible, visible (or luminous) transmittance should be considered. A low visible transmittance (usually measured in percent) creates problems of eye "fatigue" and may necessitate an increase in ambient lighting in laboratory situations. However, adequate OD at the laser wavelengths should not be sacrificed for improved luminous transmittance. For nighttime viewing conditions, the effective visible transmittance will be different since the spectral response of the eye is different. Figure 7−2 shows the scotopic (night vision) and photopic (daylight vision) responses of the eye. From figure 7–2, night vision peaks around 500 nm and daylight vision peaks around 560 nm. Blue-green filters, therefore, have higher scotopic and lower photopic transmission values than red or orange filters.

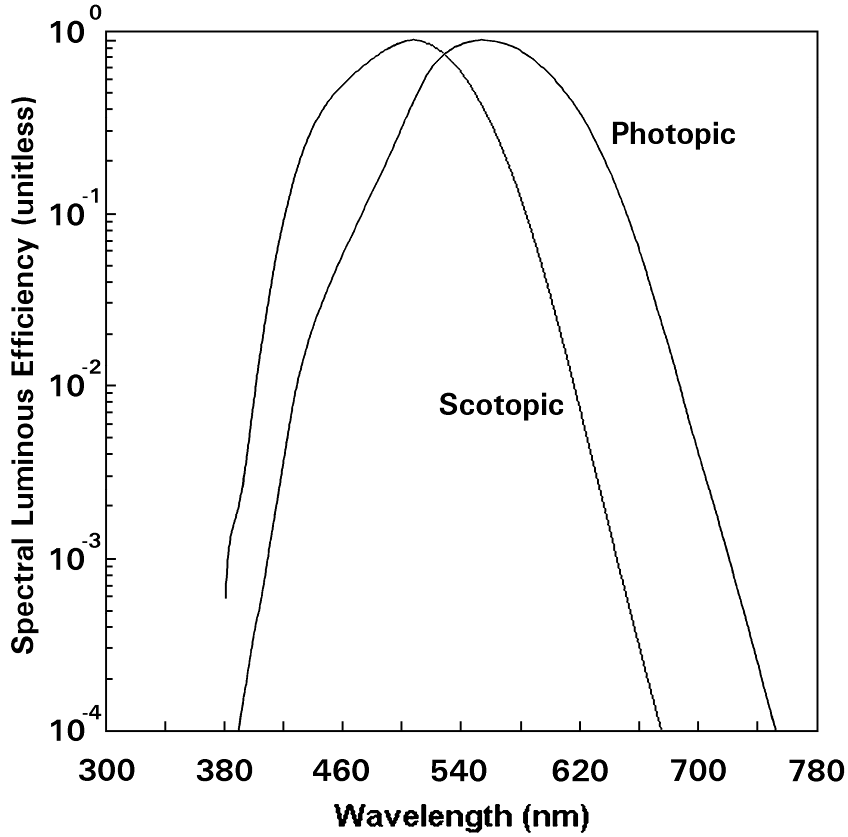


Figure 7–2. Relative spectral luminous efficiency (normalized) curves for photopic (daylight) and scotopic (night) vision

f. Laser filter damage threshold (maximum irradiance). At very high-beam irradiances, filter materials that absorb or reflect the laser radiation can be damaged. It, therefore, becomes necessary to consider a damage threshold for the filter. Typical damage thresholds from q-switched, pulsed laser radiation fall between 10 and 100 $J \cdot cm^{-2}$ for absorbing glass, and 1 to 100 $J \cdot cm^{-2}$ for plastics and dielectric coatings. Irradiances from CW lasers, which would cause filter damage, are in excess of those that would present a serious fire hazard, and therefore, need not be considered. Personnel should not be permitted in the area of such lasers. Figure 7–3 shows examples of damage to laser filters from high-beam irradiances.

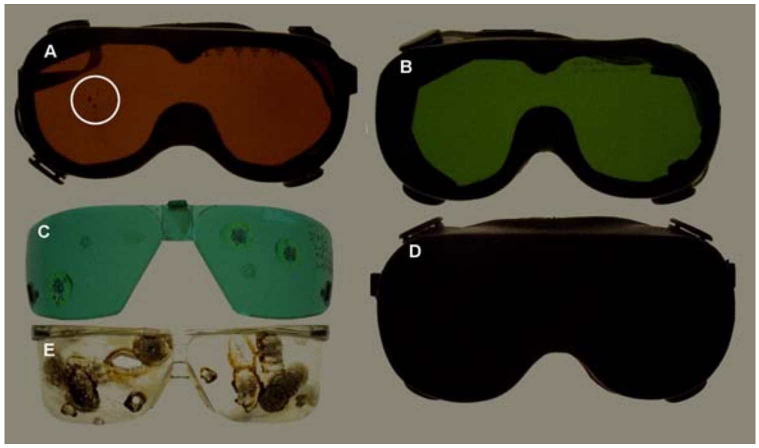


Figure 7–3. Examples of damage to laser protective devices

g. Laser protection devices. Figure 7–3 shows damage to laser protective devices. The orange goggle (example A) has damage from a Q-switched pulsed doubled Nd:YAG laser. The blue-green spectacle (example C) was also damaged by a Q-switched pulsed Nd:YAG laser. The clear spectacle (example E) was damaged with a CW carbon dioxide laser. The two pairs of goggles (examples B and D) on the right are identical. Neither have any laser damage, but the bottom goggle has become completely opaque. Some organic dyes have been known to change characteristics over a period of time.

h. Saturable absorption. In some rare instances, protective filters were shown to have densities less than specified under high irradiance levels. Saturable absorption occurs when the amount of laser energy entering the filter is high enough to saturate the dye available for absorption, thus allowing an increased level of laser energy to pass through the filter. Current military laser eye protectors (for example, BLPS, SPECS) have met OD requirements under saturable absorption testing conditions. Commercial laser eye protectors are also required to be tested for saturable absorption.

7-5. Selecting appropriate eyewear

a. Determine the laser wavelength(s) and the required OD. For fielded military laser systems, see table H−1. Ensure that the maximum exposure does not exceed the damage threshold for the filter as explained in paragraph 7−4d. There are a variety of designs available, ranging from spectacle types to heavy-duty, cover-all goggles. Some frames meet impact safety requirements. Individual requirements may necessitate choosing a particular type of design. In most military applications, it is generally recommended that filter surfaces be curved so that incident beams are reflected in a manner that reduces the beam irradiance rapidly with distance from the surface.

b. There are basically two methods for blocking laser wavelengths. The filters are either designed to selectively absorb or reflect the laser energy. The absorption method uses colored glass or plastic, and the reflective method uses dielectric or holographic coatings. Hybrid filters combine these two technologies.

c. The simplest and least expensive method of fabrication is to use colored glass or plastic absorbing filters. Glass filters are effective in resisting damage from wear, but there is a risk of the filter shattering under high-beam irradiances. Plastic filter materials generally have greater impact resistance, lighter weight, and can be molded into curved shapes easily. However, they are more readily scratched and can be affected by heat, UV radiation, and chemicals (for example, pesticides, detergents, and lotions).

d. Reflective coatings are designed to selectively reflect a given wavelength while maintaining a high visible transmission; however, angular dependence limits their use in some situations.

7–6. Army laser eye protectors

a. The Army laser eye protective systems in this section use dye absorptive technology. Since absorptive dyes provide the laser attenuation, the three-wavelength spectacle has a lower visual transmission and should only be used during the day. All lenses or outserts are ballistic protective and capable of defeating a 5.8-grain, T-37 shaped fragment-simulating projectile at 650 feet per second.

b. These systems are designed to accommodate the 5th percentile female to the 95th percentile male in one size. The clear lens provides only ballistic protection. The neutral gray lenses are the sunglasses; the blue-green lenses are the two-wavelength protectors; the brown lenses are the three-wavelength protectors. Inside combat vehicles, eye protectors may increase eye relief from sights, and some vehicle sights are already laser hardened.

(1) *Ballistic laser protective spectacles*. Soldiers requiring prescription lenses should use BLPS because it is the only laser eye protector with a prescription lens insert. The BLPS system (figure 7–4) consists of multiple spectacle assemblies available in clear, sunglass, and two or three wavelength laser protection. A hard-carrying case is available that accommodates one complete spectacle assembly (either two or three wavelength laser protection is included). All configurations are available for procurement through the Defense Supply Center, Philadelphia (NSN number series 8465–01–416–4536, 3207, 3210 and NSN 8465–01–417–4004, 9963).

Figure 7–4. Ballistic and laser protective spectacles

(2) *Special protective eyewear, cylindrical system*. SPECS (figure 7–5) is designed for soldiers who do not require prescription lenses. The SPECS system consists of a lens carrying browbar, interchangeable spatula and cable temples, a nosepiece, and four interchangeable lenses. The temples are capable of panoscopic tilt adjustment for maximum fit, comfort, and acceptance. A hard-carrying case is available that can accommodate a complete spectacle assembly consisting of a frame and two lenses. Configurations are available for procurement through the Defense Supply Center, Philadelphia (NSN number series 8465–01–416–4626, 4629, 4630, 4633, 4635, 8516, 4628, 4631, 4634, 4632, 4627).

Figure 7–5. Special protective eyewear, cylindrical system

(3) *Sun, wind, and dust goggles*. The SWDG (figure 7−6) is the standard military goggle that provides coverall laser eye protection and is compatible with standard military prescription eyewear. A rubber frame holds the lens while foam provides a seal between the face and goggle frame. The NSNs for SWDGs are in the category 8465−01.

Figure 7−6. Sun, wind, and dust goggles

(4) *Mask, chemical-biological, M40/M42 series laser/ballistic outsert*. The laser ballistic outsert (figure 7–7) can be purchased as an additional authorized list item for the M40 and M42 series mask. However, the laser/ballistic outsert is not compatible with the Red Hot mode of the thermal sight of the Bradley fighting vehicle. The NSN for the laser/ballistic outsert is 4240–01–434–1503.

Figure 7–7. M40/M42 gas mask laser/ballistic outsert

7–7. Commercial sources of laser eye protectors

For a current listing of laser eye protector manufacturers, see the USACHPPM LORP Laser Link webpage at: http://chppm-www.apgea.army.mil/laser/links/links.html.

7–8. Inspection and testing of laser eye protective devices

a. Eye protection should be checked periodically by the user for proper fit, good visibility, cracks, and discoloration.

b. The measurement of eye protection filter ODs is difficult. Testing at high ODs can result in the destruction of the filter. Because of these problems, there is no requirement that the OD of protective devices be periodically checked. The USACHPPM LORP has the capability of testing the OD and environmental stability of various types of military laser eye protectors.

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CHAPTER 8

NONBEAM HAZARDS

8–1. Introduction

a. In addition to direct hazards to the eyes and skin associated with exposure to the laser beam, it is also important to address other nonbeam hazards associated with the use of lasers (for example, cryogenics, flash lamps, chemicals, electrical, ionizing radiation, and UV hazards).

b. These hazards, such as electrocution, can be life threatening. As a result, the hazards discussed in this chapter require use of control measures different from those discussed in chapter 5.

c. Because of the diversity of these potential hazards, the LSO/RSO may employ safety, health physics, and/or industrial hygiene to aid in the control of these hazards. The following are general guidelines:

(1) Design the device or control the environment to prevent exposure of personnel to nonbeam hazards.

(2) Provide appropriate administrative controls and/or PPE when nonbeam hazards cannot be eliminated by design.

(3) Consider the use of the "buddy system" especially after normal working hours or in isolated areas.

8–2. Electrical hazards

a. The most common lethal hazard associated with the laser involves electricity. There have been several fatal accidents associated with lasers due to electrocution. Injuries have occurred when commonly accepted safety procedures were not followed as when individuals were working with dangerous, high-voltage components of a laser system. Exposures can occur when equipment covers are removed as during maintenance and/or service. Those individuals exposed can be equipment installers, users, technicians, and uninformed members of the public.

b. Electrical safety requirements are imposed upon laser devices, systems, and those who work with them by the U.S. Department of Labor, OSHA, the National Electrical Code (NEC®) (National Fire Protection Association (NFPA®) 70) and related state and local laws and regulations. (NEC® and NFPA® are registered trademarks of the National Fire Protection Association, Quincy, MA.)

8–3. Prevention of electrical shock

a. The following are general precautions:

(1) Avoid wearing rings, metallic watchbands, and other metallic objects.

(2) Use only one hand when working on a circuit or control device.

(3) Never operate electrical equipment when hands, feet, and/or body are wet, perspiring, or while standing on a wet floor.

(4) Treat all surfaces as conductive and grounded unless covered with a well-maintained, dry rubber matting of a type suitable for your electrical work.
(5) Provide a non-conductive object such as a rope, dry wooden stick, or insulated pole suitable for freeing a victim from a live conductor.
(6) Cardiopulmonary resuscitation (CPR) training should be provided for personnel routinely working with high voltage.
(7) Have an automated external defibrillator available.
b. Safe design and installation practices for high-power lasers can be found in MIL–STD–882D, MIL–STD–1425A, and the NEC. The following is a list of user precautions when servicing or maintaining high-power lasers, which employ high-voltage:
(1) Ensure that fault-current-limiting devices, such as fuses or resistors, are capable of clearing or dissipating total energy.
(2) Provide a grounded metal enclosure that is locked and/or interlocked.
(3) Enclose exposed terminals or electrical contacts.
(4) Provide suitable enclosures and barriers that protect against projectiles, such as flash lamp explosions.
(5) Keep combustible materials away from electrical contacts, capacitors, or high-power laser beams.
(6) Ensure capacitors are discharged before opening any access door.
(7) Place shorting straps at each capacitor during maintenance while capacitors are in storage.
(8) Provide reliable grounding, shorting, and interlocking.
(9) Ensure that high-voltage sources are properly labeled.
(10) Provide manual grounding equipment that has the connecting cable visible for its entire length.
(11) Supply safety devices such as safety glasses, rubber gloves, and insulating mats.
(12) Provide metering, control, and auxiliary circuits that are protected from possible high potentials even during fault conditions.
(13) Inspect routinely for deformed or leaky capacitor containers.
(14) Provide a grounding stick that has a discharge resistor at its contact point and a ground cable attached to ground. Such a grounding stick should not be used to ground an entire large bank of capacitors. Large-capacity shorting bars, with resistors, should be used. Final assurance of discharge should be accomplished with a solid-conducting-grounding rod.
c. The following potential problems have frequently been identified during laser facility audit:
(1) Uncovered electrical terminals.
(2) Improperly insulated electrical terminals.
(3) Hidden "power-up" warning light.
(4) Lack of personnel trained in current CPR practices or lack of refresher training.
(5) "Buddy system" not being practiced during maintenance and service.
(6) Improperly grounded laser equipment.
(7) Excessive wires and cables on floor that create fall or slip hazards.

8–4. First-aid procedures for electrical shock victims

a. Before touching a victim of electric shock, the circuit should be de-energized or the victim should be freed from the live conductor by using some suitable nonconductive object such as a rope, dry wooden stick, or insulated pole.

b. It is recommended that one of these nonconductive devices be provided near each high-voltage power supply (for example, in each research, development, testing, and evaluation laboratory). CPR procedures appropriate to the victim's condition should be started immediately.

8–5. Laser-generated air contaminants

a. Some applications of high-power lasers, especially in materials processing, can give rise to respiratory hazards. Laser welding, cutting, and drilling procedures can create potentially hazardous fumes and vapors. Laser-generated air contaminants (LGAC) may be produced when certain Class 3b and Class 4 beams interact with matter. While it is difficult to predict what LGAC may be released in any given situation, it is known that contaminants, including new compounds, can be produced with many types of lasers.

b. The LSO/RSO should ensure the appropriate industrial hygiene characteristics of exposure to LGAC are enforced according to federal, state, and local requirements.

(1) *Control measures for LGAC.* In general, there are three major control measures available to reduce the concentration of LGAC to acceptable levels. They are exhaust ventilation, respiratory protection, and isolation of the process.

(a) Exhaust ventilation. Whenever possible, recirculation of LGAC should be avoided. Use of enclosing hoods should be used to control LGAC whenever possible. Exhaust ventilation should ensure that all personnel exposures to hazardous concentrations of LGAC are maintained at or below the allowable levels specified by OSHA, the National Institute for Occupational Safety and Health (NIOSH), or the American Conference of Governmental Industrial Hygienists (ACGIH), or other applicable authorities.

(b) Respiratory protection. Respiratory protection may be used to control brief exposures or as an interim control measure until other engineering or administrative controls are implemented. If respiratory protection is utilized, the program should comply with the provisions specified by the U.S. Department of Labor, OSHA (29 CFR 1910.134).

(c) Process isolation. Physical barriers or remote control apparatus may isolate the laser process. Process isolation should be used with laser welding or cutting of targets such as plastics, biological material, coated metals, and composite substrates. In addition, during biomedical applications, the work area and PPE should be disinfected or sterilized immediately after use.

(2) *First aid for LGAC.* Remove the individual from the contaminated environment as quickly as possible. The rescuers should use a buddy system and be provided with adequate self-contained breathing apparatus in a contaminated atmosphere. If the person has stopped breathing or there is no pulse, begin CPR and call for help.

8–6. Collateral and plasma radiation

a. Collateral radiation (that is, radiation other than that associated with the primary laser beam) may be produced by system components such as power supplies, discharge lamps, and plasma tubes. Such radiation may take the form of X-radiation, UV radiation, IR, and visible radiofrequency radiation (RFR). In addition, when high-power pulsed laser beams (that is, peak irradiance of the order of 10^{12} W·cm^{-2}) are focused on a target, plasma are generated that also may emit collateral radiation.

b. The X-radiation emanating from laser power supplies and components should be controlled according to the provisions listed in applicable federal, state, or local codes and regulations. Collateral UV radiation emitted from laser discharge tubes and pump lamps should be suitably shielded so that personnel are not over exposed. Plasma emissions created during laser-material interaction processes may contain sufficient UV and blue light radiation to raise concern about long-term viewing without eye protection. These situations should be evaluated and appropriate control measures applied. See Technical Bulletin, Medical (TB MED) 523 for appropriate protection guides for RFR exposure.

8–7. Fire hazards

Class 4 laser beams can create potential fire hazards. Materials exposed to irradiance exceeding 10 W·cm^{-2} or beam powers exceeding 0.5 W may ignite. The use of flame-retardant materials, as defined by the NFPA, is encouraged. Fire-fighting equipment should be available.

8–8. Explosion hazards

High-pressure arc lamps, filament lamps, and capacitor banks in laser equipment should be enclosed in a housing that can withstand the maximum explosive pressure resulting from component disintegration. The laser target and elements of the optical train that may shatter during laser operation should also be enclosed to prevent injury to operators and observers. Explosive reactions of chemicals or other laser gases may be a concern in some cases.

8–9. Compressed gases

a. Many hazardous gases are used in laser applications including chlorine, fluorine, hydrogen chloride, and hydrogen fluoride. Guidelines or SOPs should be developed for safely handling these compressed gases. Typical safety hazards from using compressed gases are—

(1) Free-standing cylinder.

(2) Toxic gases from open or leaky cylinders.

(3) No remote shutoff valve.

(4) No provisions for purging gas before disconnect or reconnect.

(5) Hazardous gas cylinders not maintained in appropriate exhausted enclosures.

(6) Gases of different categories (for example, toxics, corrosives, flammable, oxidizers, inerts, high pressure, and cryogenics) not stored separately according to OSHA and Compressed Gas Association® requirements (29 CFR 1910.101). (Compressed Gas Association® is a registered trademark of the Compressed Gas Association, Inc., Arlington, VA.)

b. The following are first-aid measures for eye or skin injury from caustic chemicals:

(1) Use a deluge type eyewash and/or shower provided in a readily accessible location.

(2) Flush the eye(s) and/or skin for approximately 15 to 20 minutes immediately after exposure.

(3) Report promptly to a medical treatment facility.

8–10. Laser dyes

a. Laser dyes are complex fluorescent organic compounds that, when in solution with certain solvents, form a lasing medium for dye lasers. Certain dyes are highly toxic, carcinogenic, or mutagenic. Since these dyes frequently need to be changed, special care must be taken when handling, preparing solutions, and operating dye lasers. A material safety data sheet for dye compounds should be available for each dye. Used laser dyes should be handled in conformance with appropriate local, state, and federal guidelines.

b. The use of an airflow hood when mixing laser dyes with solvents is recommended. Most solvents are flammable liquids, and care must be taken when handling and storing these chemicals. Dye lasers containing at least 100 milliliters (mL) of flammable liquid should conform to the provisions of the NFPA: NFPA Code 30 and Standard 45 and NFPA Code 70–NEC, Article 500 (Hazardous (Classified) Locations).

c. The use of dimethylsulfoxide (DMSO) as a solvent for cyanine dyes in dye lasers should be discontinued if possible. DMSO aids in the transportation of dyes into the skin. If another solvent cannot be found, personnel should wear low permeability gloves any time contact with the solvent may occur.

8–11. Cryogenics

a. Liquids. Cryogenic liquids (especially liquid nitrogen) are used occasionally to cool lasers and frequently used to cool laser detectors. Personnel should wear quick-removal, insulated gloves when handling cryogenic materials. Clothing should not have pockets or cuffs that may catch spilled cryogenics. For pouring operations, face shields over safety glasses or chemical splash safety goggles should be worn. When dumping "inert" gases, such as liquid nitrogen, adequate ventilation should be available so that the inert gas does not replace oxygen in the work area. This oxygen replacement may go unnoticed by personnel and may lead to unconsciousness or even death. Liquid oxygen can cause combustible materials to explode when exposed to a spark. No smoking or open flame is permitted in areas where liquid oxygen is stored or used. Cryogenic mixtures, which contain oxygen or that have been open to the atmosphere for more than a few minutes, should be treated with the same precautionary measures as liquid oxygen.

b. First aid for exposure to cryogenics. If the eyes are exposed to cryogenics, the individual should be taken to a medical facility immediately. If a spill occurs on the skin, the individual's skin should be irrigated with large quantities of unheated water then apply cold compresses. If blistering occurs, the individual should be taken to a medical facility immediately.

8–12. Noise

Noise levels from certain lasers, such as excimer lasers, may be of such intensity that noise control may be necessary. (See DA Pam 40–501.)

8–13. Confining space

In many laser installations, space is at a minimum. Confining space can be a problem when working around high-voltage equipment. There must be sufficient room for personnel to turn around and maneuver freely. This issue is compounded when more than one type of laser is being operated at the same time. Whenever lasers or laser systems are used in confining space, local exhaust, mechanical ventilation, and respiratory protection should be used if LGACs are present.

8–14. Ergonomics

Repetitive procedures that may exist in certain laser operations can produce injuries such as carpal tunnel syndrome. The LSO/RSO should be aware of this and other ergonomic problems and should be familiar with appropriate user-control measures.

CHAPTER 9

SAFETY DESIGN REQUIREMENTS FOR MILITARY LASERS

9–1. Overview

a. This chapter provides safety design requirements, as contained in MIL–STD–1425A, for all DOD military lasers and associated support equipment. The purpose of the MIL–STD–1425A is to provide uniform requirements for the safe design of military equipment that incorporate lasers. These requirements apply only to laser products designed expressly for combat or combat training operations or are classified in the interest of national security. Alternate requirements are provided in MIL–STD–1425A to the FDA, Center for Devices and Radiological Health (CDRH), radiation safety performance standards prescribed in 21 CFR, Subchapter J, when the military exemption (FDA Exemption 76 EL–01 DOD) (21 CFR 1010.5) is granted to FDA Standards. These design requirements also provide uniform standards for DOD components. The ANSI Z136.1, the FDA Standard, the North Atlantic Treaty Organization STANAG 3606, or the DOD components' laser hazard classifications or categories may differ. These differences have evolved due to the rapid development of laser technology. Rather than add to this proliferation of standards with new definitions, the Army has adopted the ANSI Z136.1 laser hazard classification system as the best compromise and most current and comprehensive standard available. Military lasers, which are not exempted, will be classified according to 21 CFR 1040.10. Therefore, military lasers not covered by 21 CFR 1040.10 will use the laser hazard classification and MPE levels of ANSI Z136.1.

b. All military laser development programs should include a comprehensive system safety program according to MIL–STD–882D, to include System Safety Program Requirements that identify and control all hazards unique to the specific laser product under development.

9–2. Applicability

a. Performance requirements listed in this chapter should be applied by all DOD components to military laser products entering engineering, development, or being modified to a new use. Lasers are either exempt, as described in the current DOD Instruction (DODI) 6055.11 from the requirements of 21 CFR 1040 or are not exempt from these requirements. No laser product is certified exempt from the federal standard unless the government-contracting officer, following the provisions of the FDA exemption, provides written confirmation to the contractor (see 4–1d and 4–1e).

b. If written confirmation is not provided as part of the contract, the systems or equipment contractor may request it. Exempted systems should also include safety features, to the extent practicable, the radiation safety provisions of the FDA laser standard. This chapter does not apply to breadboard experimental lasers, but it does apply to pre-production and production prototype models.

(1) *Exempted laser products*. The requirements of MIL–STD–1425A apply to the procurement of all military laser products, including their associated support equipment, which are designed specifically for actual combat operations, combat training, or are classified in the interest of national security. All exemption requests should specify which provisions of the FDA standard are to be waived and the alternate controls that are to be applied. These should include the requirements of MIL–STD–1425A. Some examples of exempted military laser products include direct-fire simulators, rangefinders, target designators, radars, and laser countermeasures.

(2) *Nonexempted laser products*. Nonexempted laser products will be developed using the FDA Standard. The contractor will obtain any variances directly from the FDA according to procedures given in the federal regulations. Laser products used for communications, construction, maintenance, administration, medical and industrial applications, and similar purposes are not considered as combat or combat training laser products unless their designs are unique to combat operations or combat training operations.

9–3. Basic policy

Military lasers should be designed to the lowest hazard classification consistent with reliable mission accomplishment. Eye-safe emissions are a goal for all lasers used in a training environment. Laser systems and their support equipment should be designed to minimize accessibility to hazardous emissions during maintenance activities.

9–4. Tailoring

Tailoring (that is, deletion, alteration, or addition) of specific requirements in MIL–STD–1425A may be necessary for specific applications. Any such tailoring will be specified in any reference to "compliance" with MIL–STD–1425A. The specific requirements of MIL–STD–1425A that are tailored must be identified and justified, and the alternate means of assuring personnel safety during operation, maintenance, and servicing of the system must be identified.

9–5. Design requirements for exempted lasers

Lasers should meet the design (performance) requirements of 21 CFR 1040 except where such requirements restrict operational capability or security. The hazard classification, as outlined in ANSI Z136.1, should be used in selecting the applicable FDA design requirements that do not restrict operational requirements (for example, a Class 3a laser (ANSI) should apply the requirements for Class IIIa laser. Additional design requirements are contained in the following paragraphs:

a. Identification label. Every laser product should be provided with a label, permanently affixed to the device, so that it is readily accessible to view. This label should contain the full name and address of the manufacturer; the laser model and serial number; and the place, month, and year of manufacture. These may not be expressed in code.

b. Exemption label. In lieu of the certification label required by 21 CFR 1010.2, every laser product exempted under FDA Exemption 76EL–01 DOD should be provided with a label permanently affixed to the device so that it is readily accessible to view. Figures 9–1 and 9–2 are examples of exemption labels.

CAUTION
This electronic product has been exempted from FDA radiation safety performance standards prescribed in 21 CFR 1040, pursuant to Exemption No 76EL−01 DOD, granted on 26 July 1976. This product is for the exclusive use by DOD activities and is not to be sold, loaned, or donated to others.

Figure 9–1. Exemption label 1

CAUTION
Exempted from FDA 21 CFR 1040, Exempt. No 76EL−01 DOD. This product is for exclusive use by DOD activities and is not to be sold, loaned, or donated to others.

Figure 9–2. Exemption label 2

c. Location of controls. Each laser product should have operational and adjustment controls located so that human exposure to laser radiation in excess of the appropriate MPE is unnecessary for the operation or adjustment of such controls.

d. Unintentional output. Laser product design features should preclude unintentional laser output (for example, spontaneous firing).

e. Extraneous radiation and beam irregularities. All lasers and associated optics will be designed so that external secondary beams are not generated unless necessary for the performance of the intended function(s). The use of focused beams, hot spots, and collateral radiation should be minimized. Laser systems that employ frequency shifting or harmonic multipliers to alter the fundamental output wavelength should reduce unnecessary emissions to below the MPE.

f. Unwanted modes. The laser system should be designed to preclude unintentional self-oscillation, mode-locking, double-pulsing, or unwanted modes.

g. Interlocks. Protective housings should be interlocked to protect personnel from high voltage sources and unnecessary laser and collateral radiation. Aural or visual indication of interlock defeat should be provided. These visual indicators will be readily visible while wearing necessary laser-protective eye devices. Interlocks should return to their normal operation when the access cover door is replaced.

h. Optical ports. Viewing ports and display screens, which allow the operator to view laser radiation, should limit personnel exposure to below the appropriate MPE.

i. Optical sights. Laser product pointing or viewing optics having a magnifying power exceeding 1.0 should include a built-in laser safety filter within the optical train, which protects the operator from reflections from specular surfaces or exposures to similar lasers during Force-on-Force training. The built-in safety filter will keep transmitted laser radiation levels at or below the appropriate MPE for that particular laser system. Such filters should not significantly impair visibility and should be permanently attached or designed so that the optical train cannot be assembled without the filter. The laser system or individual sight shall be marked to indicate the level and type of protection afforded in the viewing optics either by OD and wavelength or by the use of a filter-marking code. This filter-marking code shall consist of a single-letter-laser-safety code on the first line and an individual filter code on the second line consisting of a two letter design code, a five digit manufacturing code, and a five digit lot number. Minimum ODs for the single-letter-laser-safety codes for both magnifying and non-magnifying optics are provided in tables 9–1 and 9–2, respectively. These codes may not fully describe the level of laser protection in the sight.

Table 9–1
Minimum optical density values for magnifying optical sights

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

Note: The OD values given above are for the entire system. For example, a filter with 4.7 OD at 694.3 nm a 5.8 OD at 1064 nm with essentially no protection in the 800 nm–950 nm band would be Category D when used in conjunction with a sight with an intrinsic OD 0f 0.27 in the near IR (800 nm–950 nm) due to the intrinsic filtration of the sight.

Table 9–2
Minimum optical density values for non-magnifying optical sights

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

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

j. Nonbeam hazards. Electronic systems should be designed according to MIL–HDBK–1454A. Other hazards associated with the laser and its operation should have engineering controls according to MIL–STD–882D. See chapter 8 of this bulletin for additional information on nonbeam hazards.

k. Laser warning labels. Laser warning labels for exempted lasers should provide clear instructions to the operators, maintainers, and potential bystanders to preclude laser injury. Legible labels should be permanently affixed or inscribed on laser housings and readily accessible for viewing when the product is fully assembled. There are two types of warning labels required for exempt lasers—

(1) *Hazard warning label*. This label describes the potential hazard of the device and should be affixed near the fire button. The label should include the type of laser, and the word "VISIBLE" or "INVISIBLE", as appropriate, should precede the word "RADIATION." The label should also contain an appropriate instructional safety statement or control message for the operator or bystander as applicable. The ANSI classification will be displayed in the lower right corner of the warning label rather than the FDA class (for example, "ANSI Class 2 Laser Product"). Numerical output information, such as wavelength(s) and maximum power output (when unclassified) should be located along the lower edge in a smaller font. The following examples show the suggested ANSI warning label colors. Exempt lasers often use muted colors for the labels.

(a) Class 1 label. Class 1 lasers should have a label that simply identifies the laser as a Class 1 product. An example is shown in figure 9–3.

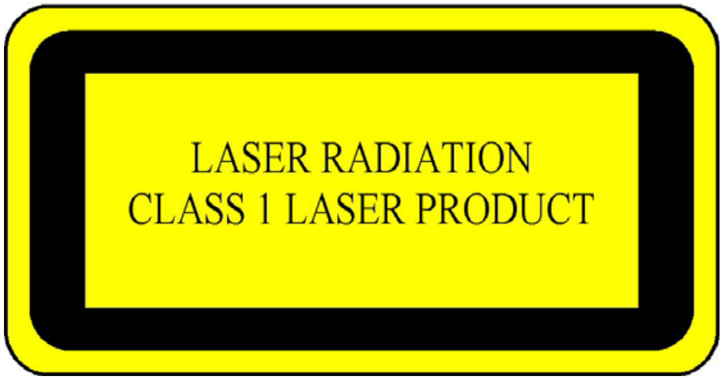

Figure 9−3. Example of a label for Class 1 lasers

(b) Class 2 label. Class 2 lasers require a "CAUTION" label with an instruction not to stare into the beam. An example is shown in figure 9–4.

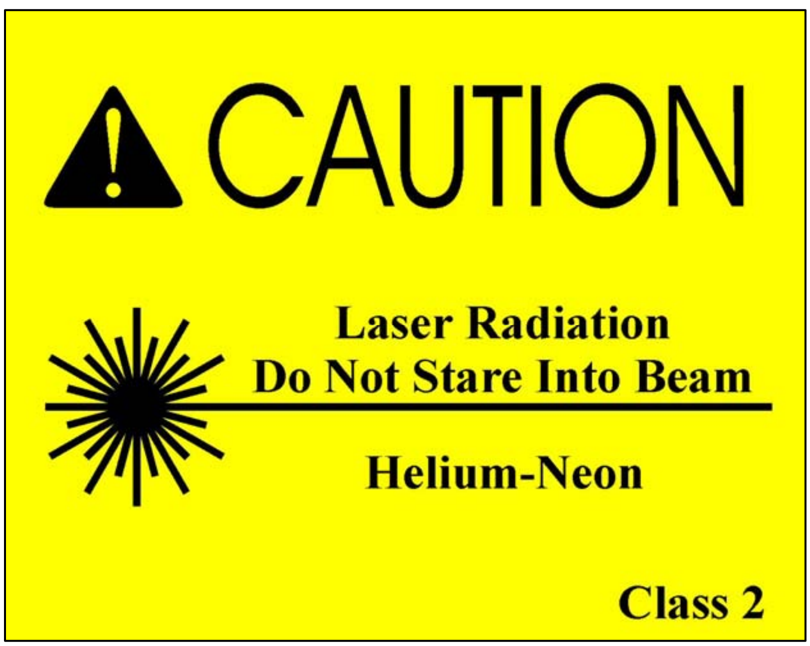

Figure 9–4. Example of a warning label for Class 2 lasers

(c) Class 3a label. Class 3a lasers require either a "CAUTION" or "DANGER" label. A CAUTION label is required if the appropriate MPE is not exceeded beyond 10 cm from the exit port in the beam path except for optically aided viewing. A sample CAUTION label is shown in figure 9–5. A DANGER label is required if the appropriate MPE is exceeded beyond 10 cm from the exit port in the beam path. A sample DANGER label is shown in figure 9–6.

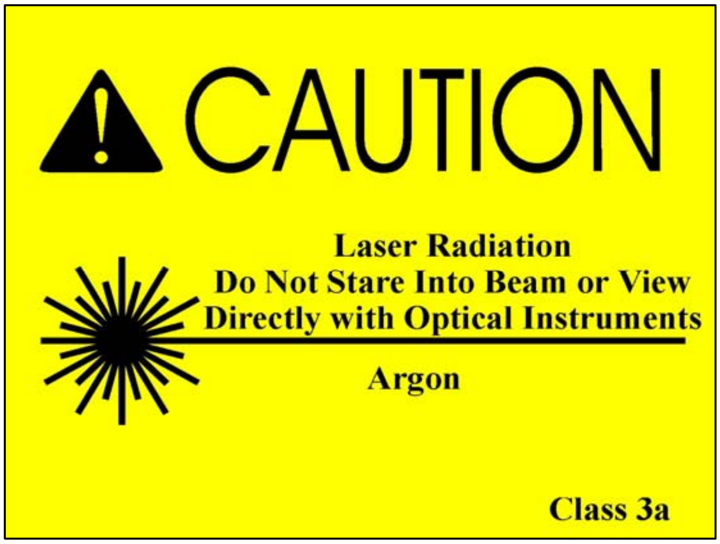

Figure 9–5. Example of a warning label for Class 3a visible (400 nanometers to 700 nanometers) lasers

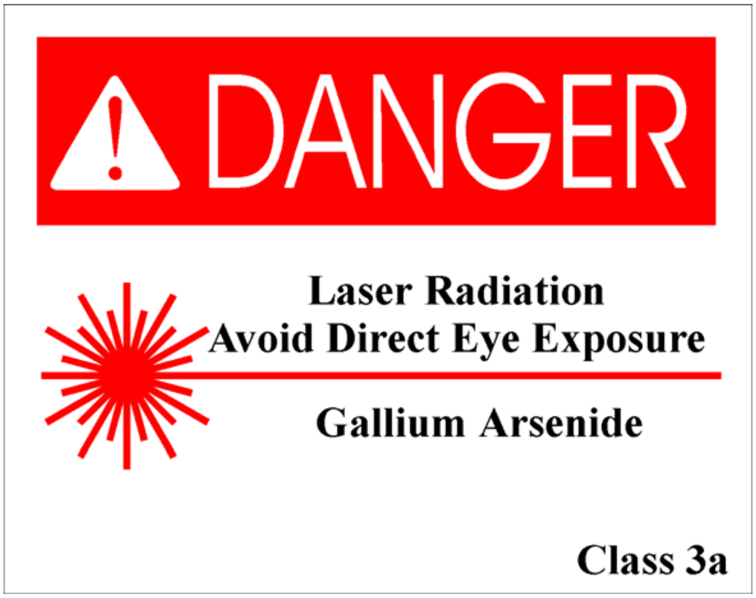

Figure 9–6. Example of a warning label for Class 3a infrared (> 700 nanometers) and ultraviolet (< 400 nanometers) lasers

(d) Class 3b and 4 labels. Class 3b and Class 4 lasers require a "DANGER" label. A sample DANGER label is given in figures 9–7 and 9–8. See paragraph 9–6 for more detailed information on Class 3b and 4 requirements. Figure 9–9 depicts two typical warning labels used in Europe.

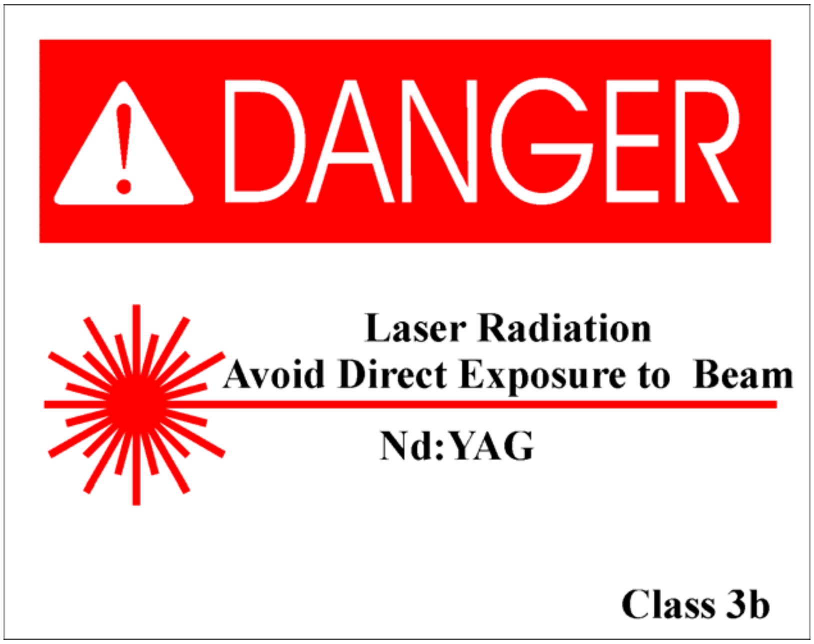

Figure 9–7. Example of a warning label for Class 3b lasers

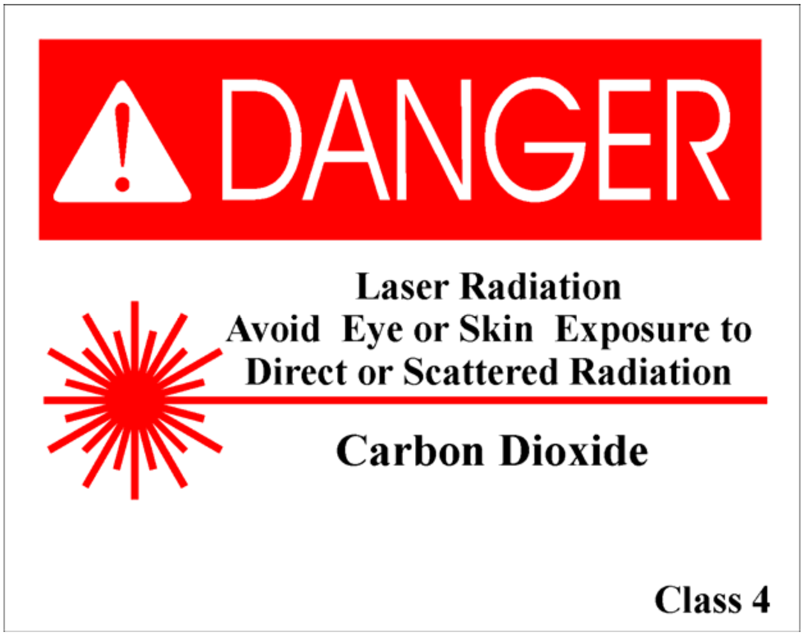

Figure 9–8. Example of a warning label for Class 4 lasers

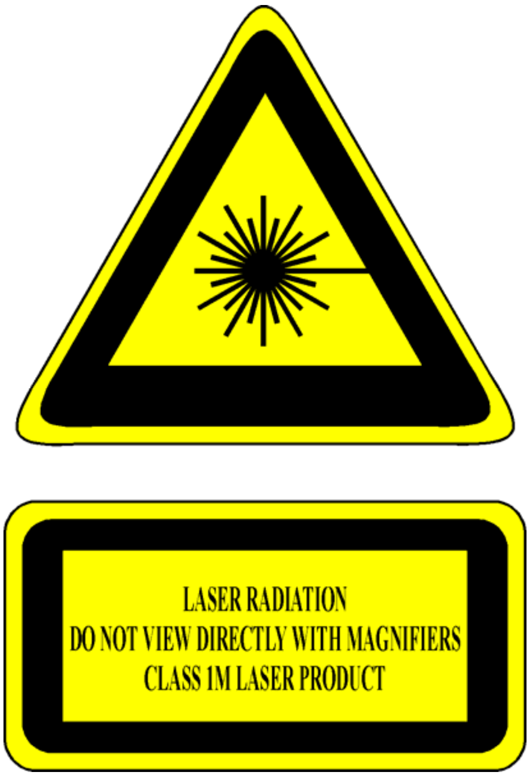

Figure 9–9. Example of typical International Electrotechnical Commission warning labels

(2) *Exit port label*. This label should identify the exit port and be affixed near the exit port. The placement of the exit port label should not cause exposure to laser radiation in order for personnel to read the label. These labels are required for Class 2, Class 2M, Class 3a, Class 3b, and Class 4 lasers. Class 1 and 1M lasers that emit invisible laser radiation should have an exit port label.

(3) *Interlock label.* If a Class 1, Class 1M, Class 2, Class 2M, or Class 3a (3R) laser has a defeatable interlock, which when defeated allows access to Class 3b or Class 4 emission levels, then an additional label, as illustrated in figure 9–10, should be installed on or near the access panel—

DANGER Hazardous Laser Radiation When Open and Interlock Defeated, Avoid Eye or Skin Exposure to Direct or Scattered Radiation

Figure 9–10. Example of an interlock label

l. Label colors. When labels may compromise camouflage, muted colors appropriate to the camouflage paint scheme may be used.

m. Classified. Information classified in the interest of national security will not be divulged on any label.

n. Alternate labeling. Nonexempted lasers may incorporate military labeling when alternate labeling has been requested by the manufacturer and approved as a variance by FDA according to 21 CFR 1040.

9–6. Design requirements for Class 3b and Class 4 exempted lasers

a. Warning labels. Class 3b and Class 4 lasers, as defined by ANSI, should be provided with a label similar to the examples illustrated in figures 9–7 and 9–8. The warning labels should contain warnings relevant to the specific situation. Labels may be intended for personnel operating lasers or others who may be exposed. For example, the operator warning for Class 3b and Class 4 ground target designators should read, "DO NOT AIM AT PERSONNEL OR FLAT GLASS SURFACES." The bystander warning for visible and near-infrared (400 nm–1400 nm) Class 3b and Class 4 lasers should read "DO NOT LOOK INTO EXIT APERTURE." Infrared (1400 nm–1 mm) and ultraviolet (200 nm–400 nm) Class 3b and Class 4 lasers that pose a skin hazard should have a label stating "DO NOT EXPOSE EYE OR SKIN TO DIRECT OR SPECULARLY REFLECTED BEAMS."

b. Danger labels. The "DANGER" labels should be printed on a white background with a bright red oval around the word "DANGER" and should contain a red "starburst" and black lettering. When warning labels compromise camouflage, muted colors (that is, olive drab) should be used. The ANSI laser hazard classification, wavelength(s), and maximum radiant power or energy should be added along the lower edge of the label if this information is not classified in the interest of national security.

c. Unintentional output. No single operator error or material failure should cause unintentional laser output that exceeds the MPE. At least two operator actions will be required to cause the laser to function. One of these should serve as a laser-arming control. Laser output should not be possible when this control is in the safe position. Power control switches may serve as laser-arming controls. Master key controls will be required only when specified by the procuring activity.

d. Laser fire switch. The laser fire switch or trigger should be clearly identified and should be physically protected to prevent accidental activation. When possible, the switch should be a protected positive-action ("dead-man") type requiring continuous operator intent to operate the laser button. Laser activation circuitry should be of a fail-safe design so that continual depression or short-circuiting of the fire control switch will not cause repeated emissions. However, when operational considerations preclude the use of a dead-man switch, a toggled switch may be used, providing that adequate design safeguards are furnished to prevent long-term inadvertent lasing (for example, through "watchdog" timers and system logic switching).

e. Exit-port cover. An exit-port cover should be provided, which is permanently installed within the laser product or attached to the device housing and which is capable of preventing access by any part of the body to all laser radiation in excess of the MPE. An example of such a device is a swivel-beam stop, which can be latched over the laser-output port, or a threaded attenuating cap with chain. Rotation of the laser to an enclosed stowed position is also acceptable. The cover chosen should clearly indicate when it is in place.

f. Remote control connector. A readily available remote control interlock capability should be incorporated on all Class 3b and Class 4 laser products (or alternatively on auxiliary power supply systems for laser products) that can be used during maintenance or service to interlock the system via an electrical cable to entrance door switches of a laser maintenance or service area. This requirement is not essential if the laser is always directed into an interlocked test set enclosure for maintenance or service procedures. When the terminals of the connector are not electrically joined, human access to all laser radiation and collateral radiation in excess of the MPE should be prevented. Once disconnected, the system should not automatically reactivate without an intentional reset.

g. Boresight. Boresight alignment and retention should be designed consistent with system mission requirements and should be considered a safety-critical item.

h. Emission indicator. Laser emission indicators should be provided to inform the laser operator when the laser is prepared to fire (armed) and when the laser is actually emitting optical radiation (firing). Indicators should be aural or visual (tone or light), or as specified by the procuring agency, and should not compromise camouflage. If visual indication is selected, the source should be visible under daylight as well as nighttime conditions. The source should also be visible when viewing through laser protective eyewear designed specifically for the wavelength(s) of the emitted laser radiation if such eyewear is required to be worn during operation, maintenance, or service.

i. Visual indicators. Visual indicators should be located so that viewing does not require personnel exposure to laser radiation in excess of the MPE. A light could differentiate between "armed" and "firing" states by emitting either a continuous or blinking display. The display could be a part of the sight reticle or its outer ring. When armed and firing are differentiated by a continuous tone or light and an intermittent tone or blinking light, the continuous tone or light should mean "armed," and the intermittent tone or blinking light should mean “firing.”

j. Airborne lasers. Laser systems installed on aircraft should be designed to prevent laser output while the aircraft is not airborne. However, a defeating switch (that is, protected from inadvertent activation) may be provided to override the ground interlock to aid ground operation, maintenance, or service.

k. Beam pointing. Laser product design features should incorporate controls to optimize positive operator control of beam pointing. This should include a means of ensuring boresight retention and the safety of software systems. For systems with automatic target tracking capability, an automatic disable capacity should be incorporated to inhibit laser firing if target tracking outside the system specifications occurs or when the laser-sight line reaches the gimbal limits or the system mask limit. At least two independent systems should be capable of disabling the laser if no hardware stops are installed. A provision to override these automatic features during combat is permitted.

l. Scanning beams. Laser products that use a beam-scanning technique should include a feature that terminates or reduces the beam output to the MPE immediately upon the cessation of scanning or upon scanning pattern irregularities such as a change in either scan velocity or amplitude. This requirement applies if such irregularities are not normal to the operation of the laser product, and also, if the unintended pattern changes would increase the hazard potential of the laser product.

m. Training mode. When a training mode for the laser is required by the contract, provisions will be made to reduce the hazardous emissions to the lowest level consistent with training requirements. This may be accomplished through the use of a beam attenuator, beam expander, or diffuser on the laser. Alternatively, separate systems such as less hazardous lasers and television cameras may be used to meet this requirement. When the laser can be used in both a mission and training mode, a visual indication should be provided to inform the operator and outside observers that the laser is positively in the training mode. A special tool should be required when switching from a training mode to a tactical mode when the tactical mode is Class 3b or Class 4.

n. Determination of nominal ocular hazard distance. An estimated value of NOHD may be calculated using the appropriate laser system output parameters with regard to the environmental conditions under which the laser is to be used. While contractor determination of NOHD may be used during system design, the final NOHD must be certified by the government based upon a test (performed by the USACHPPM LORP) prior to government personnel exposure.

o. Optical sights. Aiming optics should employ a reticle that can be viewed under any illumination condition for which the laser is designed. The reticle should not impair any dark adaptation of the observer's eye. Calibrated reticles should be considered so that the laser operator can determine the proximity of the laser beam to target buffer zones.

9–7. Laser test sets

Design of laser test sets should ensure that laser radiation emitted during maintenance or service is no greater than the MPE. Such equipment should confine the laser radiation within an opaque enclosure, which is adequately interlocked to prevent levels in excess of the MPE. Such an enclosure should be provided with appropriate exterior warning indicators and labels. Enclosed equipment can eliminate the need for specialized facilities as described in chapter 5 of this bulletin.

CHAPTER 10

DESIGN REQUIREMENTS FOR ASSOCIATED SUPPORT EQUIPMENT

10–1. Introduction

a. Support equipment includes test equipment, fixtures, and other enclosures procured to support laser systems. Support equipment should be designed to meet the following requirements based upon the hazard classification as defined by ANSI Z136.1 of the laser(s) to be used with such equipment.

b. The support equipment in conjunction with the laser system should meet the requirements of paragraph 9–5 and should be considered nonmilitary exempt under FDA Exemption #76 EL–01 DOD unless this equipment is used solely in support of exempted lasers.

10–2. General requirements

a. Design goal. Design of associated support equipment should ensure that laser radiation emitted during maintenance or service is no greater than the ANSI AEL for Class 1, and collateral radiation is not in excess of applicable limits when practicable. Such equipment should confine the laser radiation within an opaque enclosure, which is adequately interlocked to prevent levels in excess of the ANSI AEL for Class 1 when the enclosure is removed. Such an enclosure should be provided with appropriate exterior warning indicators and labels. Enclosed equipment can eliminate the need for specialized facilities.

b. Nonbeam hazards. Other nonbeam hazards from the support equipment and the operation, maintenance, or service of the laser should be controlled by suitable engineering according to MIL–STD–882D. Adequate instruction as to safe techniques and personnel protective means should be included in all technical references (manuals) and plainly marked on the laser product when potentially hazardous areas are accessible.

10–3. Requirements for Class 1, Class 2, and Class 3a laser support equipment

Support equipment, which is classified as Class 1, Class 2, or Class 3a, should meet the requirements of paragraph 9–5.

10–4. Requirements for Class 3b and Class 4 laser support equipment

a. Test equipment. Laser system test equipment for boresight and laser-performance testing should enclose or attenuate the beam to limit personnel exposure to below the AEL for ANSI Class 1 and should be interlocked to the laser to prevent inadvertent laser operation outside the enclosure if the test equipment is not used in a closed installation.

b. Interlock switch. A safety (access) interlock switch should interface with ANSI Class 3b and Class 4 laser systems under test, such that inadvertent removal of test sets or poor connection will terminate or limit the laser output to the ANSI AEL for Class 1, or to the ANSI AEL for Class 2 if applicable.

c. Warning system. A warning system (for example, flashing light, audible indicator or other physical indicator external to the test set) will be activated immediately prior to operation of the laser and will remain activated until the laser output has been reduced to the ANSI AEL for Class 1 or to the ANSI AEL for Class 2, if applicable. The warning system should be designed not to attract personnel attention in such a manner as to create a potential hazard.

d. Operation switch. All equipment used as support equipment for laser hardware, which could directly activate the laser, should incorporate a positive action ("dead-man") switch that must be activated when laser firing is desired. When a dead-man switch is not incorporated, an emergency cut-off switch should be provided, which allows emergency cut-off of laser output in excess of the ANSI AEL for Class 1 or Class 2 as appropriate. This switch should be readily accessible from the operator's position and should permit one-step operation. Normal power or control switches may fulfill this function (see MIL–STD–1425A).

e. Master switch. A key-lock master switch should be required to prevent unauthorized activation of any test facility component used to supply power directly to the laser that is necessary for its operation.

f. Beam stops. The laser beam should be terminated by a beam stop, which is diffuse (nearly a Lambertian surface), having a low value of reflectance at the laser wavelength(s). Where possible, such a beam stop should also be fire resistant and unable to emit toxic or carcinogenic fumes when exposed to the laser(s) for which the beam stop has been designed. The beam stop should be marked for the type(s) and power level(s) for which it is procured. Firebrick, certain ceramics, and graphite are examples of backstops for high-power infrared lasers. However, certain firebrick may contain beryllium compounds, which can produce hazardous beryllium fumes. Where toxic gases cannot be prevented, appropriate control measures for the protection of personnel, such as appropriate exhaust ventilation, should be engineered into the system.

CHAPTER 11

LASER SAFETY IN HEALTHCARE FACILITIES

11–1. Introduction

a. This chapter provides guidance for the safe use of lasers and laser systems that are used in healthcare facilities. It applies to those personnel associated with the installation, operation, maintenance, and service of healthcare laser systems (HCLSs). An HCLS, as referred to by ANSI, is an apparatus which includes—

(1) A delivery system to direct the output of the laser.
(2) A power supply with control and calibration functions.
(3) Mechanical housing with interlocks.
(4) Associated fluids and gases required for the operation of the laser.

b. An HCLS certified for a specific class by a manufacturer according to the FLPPS (21 CFR 1040.10 and 1040.11) fulfills all classification requirements of this document.

c. Modified lasers should be reclassified according to this document or the most current ANSI Z136.1. The FLPPS requires that the operating manuals for HCLSs contain adequate instructions for assembly, operation, and maintenance. These instructions should include clear warnings with precautionary statements to avoid possible exposure to hazardous levels of laser and/or collateral radiation.

d. If information on operation and/or safety is not available or is lacking appropriate detail and the manufacturer and/or distributor cannot or will not provide the necessary information, the LSO/RSO should provide alternative safety instructions for the operation of the HCLS based on ANSI Z136.3. The LSO/RSO may also provide additional information, training, and protocols depending on the policy of the organization responsible for the HCLS use.

e. HCLSs, in general, have short focal-length optical systems to deliver laser energy to the patient. HCLSs, because of the short focal-length optical systems, have hazard distances of at most a few meters. As a contrast to HCLSs, tactical military lasers have collimated beams with minimal beam divergence and, therefore, hazard distances extend kilometers away from the source. In addition, HCLSs may operate with short open beam paths, as in laser photocoagulation. Other delivery systems may use fiber optic cables to deliver laser energy through body cavities to the interior of the patient. In general, fiber optic systems do not expose anyone, except the patient, during normal operation (that is, intact fiber). Fiber optic cables should be used with care to avoid cable breakage, which could expose personnel to hazardous laser energy.

11–2. Healthcare laser system–laser hazard classification

a. General classification scheme. The classification scheme is based on the ability of the primary laser beam or reflected primary laser beam to cause eye or skin injury. Many lasers used in surgery are ANSI Class 4 laser systems since most are designed to alter biological tissue. The

HCLS laser hazard classification scheme information presented in this section is based entirely on laser radiation and does not include other nonbeam hazards. HCLSs manufactured or marketed in the United States for the U.S. Army must comply with all provisions of the FLPPS for Light Emitting Products.

b. U.S. Army classification scheme. HCLSs certified for a specific class by a manufacturer according to the FLPPS may be considered as fulfilling all classification requirements of the U.S. Army. In cases where the HCLS classification is not provided or has potentially changed, the U.S. Army will classify the HCLS using the ANSI Z136.1 classification scheme. The USACHPPM LORP is responsible for classifying HCLSs when laser classification is not available.

11–3. Effects of medical lasers on the biological system

a. General. Several properties of lasers contribute to their usefulness in the healthcare environment. The wavelength, power/irradiance, and mode (that is, pulsed or continuous wave) are the three major factors that contribute to the laser's medical use. The objective tissue properties of absorption, reflection, and transmission also play a significant role in determining a laser's medical application. Additional factors that influence the laser/tissue interaction include variations in individual pigmentation, circulation, and thermal conductivity.

b. Wavelength. Laser wavelengths interact with tissue differently, depending on the type of tissue, thereby, playing an important role in the hazard determination. For example, in the case of a laser directed at the human eye, a far-infrared laser will not generally be considered a retinal hazard, while a visible laser will be a retinal hazard. A carbon dioxide (far-infrared at 10,600 nm) laser will interact with the cornea, the first tissue in the beam path. Alternatively, a doubled Nd:YAG (532 nm) laser will pass through the cornea and focus (~100,000 × magnification) onto the retina. Photosensitizing drugs are wavelength dependent and can affect the tissue's usual interaction to lasers.

c. Power and irradiance. The power and irradiance level of a laser system have a direct effect on the target tissue. The primary effect of the power and irradiance on biological tissue is thermal. For example, the energy from a carbon dioxide laser is strongly absorbed by water. Most biological cells consist of 80 percent or more water. When the carbon dioxide laser energy strikes tissue, the tissue absorbs the energy causing the cells to effectively boil. The boiling causes vaporization. It follows, the higher the power and/or irradiance, the more rapid the cellular vaporization. By controlling the irradiance and the spot size, the depth of vaporization and the width of vaporization can be controlled.

d. Mode (CW/pulsed). The mode of HCLS plays an important role in its use. A laser that delivers high-powered pulses in a very short duration (photodisrupter) can cause tissue to ionize. The effect can be used to section transparent membranes and adhesions in the eye. A CW laser can be used to precisely cauterize and vaporize tissue with a continuous beam of energy.

e. HCLS typical uses. Lasers for HCLSs are selected based on the specific laser/tissue interaction mechanisms. The aforementioned properties of the laser will dictate the mechanism and/or mechanisms that will most likely occur. The mechanisms typically involve photochemical (including photodissociative), photodisruptive, and thermal effects. Photochemical effects include photoablation (photodissociation) and photodynamic therapy.

Thermal effects include coagulation or vaporization of tissue. Table 11–1 shows several lasers that may be found in a healthcare environment. The list is only general in nature and is representative and not all-inclusive.

Table 11–1
Typical healthcare laser systems

Laser Type	Typical Medical Use	Mode	Wavelength Range	Wavelength (nm)
Excimer: Argon Floride	Photorefractive Keratectomy - (corneal surgery); tissue removal; Laser-Assisted InSitu Keratomileusis (LASIK) eye surgery.	Pulsed	UV-C[1]	193
Excimer: Krypton Flouride (KrF)		Pulsed	UV-B[2]	248
Excimer: Xenon Chloride (XeCl)		Pulsed	UV-A[3]	308
Helium Cadmium (He-Cd)		CW	UV-A	325
Excimer: Xenon Flouride (XeF)		Pulsed	UV-A	351
Dye-Tunable	Dermatology; blood vessel reduction; treatment of scars (keloids) and vascular lesions; photodynamic therapy.	CW/Pulsed	VIS[4]	400-900: typically 504, 577, 585, 590, 720, or 750
Argon	Dermatology; endoscopy; photocoagulation of the retina; plastic surgery.	CW	VIS	488, 514
Copper Vapor	Dermatology; photodynamic therapy.	CW	VIS	510, 578
Doubled Nd:YAG (KTP)	Dermatology; tattoo pigmentation breakup; blood vessel reduction; treatment of vascular lesions; endoscopy.	Pulsed	VIS	532
Gold Vapor	Photodynamic therapy.	Pulsed	VIS	628
Laser Diodes Gallium Arsenide (GaAs); Gallium Indium Arsenide (GaInAs)	Dermatology; other surgical applications.	CW/Pulsed	VIS-NIR[5]	630-950
Helium Neon (He-Ne)	Used for aligning and aiming other lasers.	CW	VIS	633
Ruby	Dermatology; tattoo pigmentation breakup; blood vessel reduction; treatment of vascular lesions.	Pulsed	VIS	694
Alexandrite		Pulsed	VIS	720 - 800
Nd:YAG	Dermatology; endoscopy; selective tissue vaporization/coagulation; photodisruptor used in ophthalmology.	CW/Pulsed	NIR[6]	1064
Erbium:YAG	Tissue coagulation and vaporization; arthroscopy.	Pulsed	MIR[7]	1540

Table 11–1
Typical healthcare laser systems (continued)

Laser Type	Typical Medical Use	Mode	Wavelength Range	Wavelength (nm)
Holmium:YAG		Pulsed	MIR	2140
Hydrogen Flouride (HF)		Pulsed	MIR	2730
Erbium:YAG		Pulsed	MIR	2940
Carbon Dioxide (CO_2)	Many applications: dermatology; tissue vaporization; coagulation; excision; incision; ophthalmology.	CW/Pulsed	FIR[8]	10,600

Notes:
[1] UV–C ─ ultraviolet radiation (100 nm–280 nm)
[2] UV–B ─ ultraviolet radiation (280 nm–315 nm)
[3] UV–A ─ ultraviolet radiation (315 nm–400 nm)
[4] VIS ─ visible
[5] VIS–NIR ─ visible near-infrared
[6] NIR─near-infrared
[7] MIR─mid-infrared
[8] FIR─far-infrared

11–4. Healthcare laser system–non-surgical lasers

a. A variety of lasers, besides those with direct medical uses, are operated in healthcare environments. The most common non-surgical HCLS is the alignment laser. Alignment lasers are used to aim other HCLSs, such as a carbon dioxide cutting laser, or they are used to precisely position patient and equipment for nuclear magnetic resonance or positron emission tomography measurements.

b. Alignment lasers used in HCLSs are typically ANSI Class 1, Class 2, or Class 3a. The older style helium neon alignment lasers are usually Class 2; the newer diode alignment lasers are typically Class 3a.

11–5. Medical lasers–control and operation of healthcare laser systems

a. Control of healthcare laser systems. Control measures for HCLSs are no different than control measures for lasers in general. The healthcare environment, however, is a unique setting where hazardous lasers are used and patients are treated therapeutically with levels far above occupational exposure limits. Controls measures generally include engineering controls and administrative controls. The administrative controls include guidelines or SOPs, controlled areas, warning signs and labels, and laser protective devices. General explanations of control measures are explained in chapter 5. The presence of healthcare personnel, patients, and patient associates influence the total hazard evaluation, and thus, the control measures implemented. Comments provided here apply only when the equipment is used as intended. Maintenance and special operation must be considered separately.

b. Engineering controls. Engineering controls are the preferred method of control since they require no user action. Due to the nature of HCLSs, administrative controls are almost always necessary. When considering controls, the ability level of personnel to understand the controls (such as, written warning signs), the limits of the engineering controls, and the availability of laser protective devices should be considered in the analysis. In addition, the functionality and potential failure of the engineering controls should be considered. For example, many HCLSs deliver the laser energy through a fiber optic cable. The possibility of the fiber breaking or cracking and delivering laser energy in an unintended direction may need to be considered when determining the NHZ. ANSI Z136.3 lists several nonbeam hazards associated with HCLSs that may need to be considered when determining an NHZ. Chapter 8 lists several general nonbeam laser hazards.

c. Requirements. The U.S. Army requirements are outlined below—

(1) *Department of the Army policies and procedures.* Requirements for lasers used by the U.S. Army are outlined in AR 11–9 and DA Pam 40–11. A major implication of AR 11–9 for the laser safety program is the explicit statement: "The design of an Army laser safety program will follow applicable guidelines in ANSI Z136.1 and ANSI Z136.3."

(2) *Training.* Training will be commensurate with responsibilities.

(3) *Medical surveillance.* Identify laser workers according to appendix C of this document. The occupational health program of the installation or activity generally maintains this program.

(4) *LSO/RSO.* The LSO/RSO is responsible for the laser safety program and implementation of controls.

11–6. Healthcare laser systems–multi-wavelength laser protective eyewear hazards

a. The greatest increase in medical-laser use recently has been in dermatology and plastic surgery. Potential ocular injuries are more likely to occur to physicians (or nearby personnel) while using multiple laser wavelengths to perform surgery. This section is intended to inform personnel on the multi-wavelength hazards from lasers used for medical purposes, especially dermatological surgery such as tattoo removal or treatment of vascular lesions.

b. Current guidelines, SOPs, and policy doctrine may not sufficiently address or stress the importance of choosing and wearing only the correct laser protective eyewear, especially during multi-wavelength laser procedures. Healthcare administrators and healthcare providers should ensure that appropriate safety protocols are in place and are being rigorously followed.

(1) *Hazard identification.* The potential for injury while using these lasers for medical purposes greatly increases when the specific treatment requires the use of more than one wavelength of laser energy, such as in tattoo removal. Typical laser protective eyewear is wavelength specific. An individual laser-eye protector does not protect against all types of lasers. For the case of a dermatological treatment, several laser wavelengths may be used during one session. The hazard arises when the laser protective eyewear does not protect against the current wavelength being used for treatment. Due to operator fatigue and/or lack of situational awareness, the simple task of switching to the appropriate laser-eye protector for the laser being used or ensuring the laser protective eyewear offers multi-wavelength protection may not always be rigorously followed. As a result, retinal injuries have allegedly occurred.

(2) *Safety practices.* Safety guidelines for the use of lasers for medical purposes should be reviewed. The guidelines should ensure that protocols and procedures address the problem of assuming that appropriate laser protective eyewear is always chosen for the selected wavelength

of the laser. Lasers should be clearly labeled as to their emitted wavelengths and type of laser. Further labeling should clearly indicate which wavelength is selected and in use. Laser protective eyewear should be clearly marked and should indicate the wavelength and type of laser protection that is afforded, as well as the OD for the protection. (Note: OD is wavelength dependent.) Current laser eye protective technologies offer multi-wavelength protection. Generally, however, a single laser eye protective device will not cover all wavelengths. The guidelines or SOP should address this issue where applicable. (See appendix D for sample guidelines.)

(3) *Additional hazards for medical lasers*. Use of high-power lasers may cause diffuse reflection hazards (thus, posing hazards for all personnel within the NHZ). Assessment of the procedures used and operating conditions present (including reflections from surgical instruments, apparatuses, and biohazard membranes) should be addressed.

CHAPTER 12

LASER SAFETY PROGRAM–LSO/RSO RESPONSIBILITIES

12–1. Introduction

a. The LSO/RSO responsibilities are discussed with regard to laser systems. A complete description of LSO/RSO duties is beyond the scope of this chapter; however, a brief overview of LSO/RSO duties is provided below. For more detailed guidance, please consult the references listed in paragraph 12-1b(2). Any questions can be referred to the USACHPPM LORP at http://chppm-www.apgea.army.mil/laser/laser.html.

b. Other high intensity optical sources (HIOS) can be hazardous (for example, Xenon arcs, UV–A/UV–B phototherapy booths, UV germicidal hoods, infrared countermeasure devices, and UV lamps). Guidance on these HIOS can be found in the current: ACGIH—Threshold Limit Values; ANSI/Illuminating Engineering Society of North America (IESNA) RP-27.1-1996 ; and ANSI/IESNA RP–27.3-96.

(1) *Fundamentals*. A good laser safety program will have the following key fundamental elements at all levels of the program—

(a) Knowledge about the general hazards and where to find needed information.

(b) Assessment of the specific hazards.

(c) Implementation of a level of protection from the known hazards.

(2) *Regulations and references*. ANSI Z136.1 and ANSI Z136.3 provide guidance to establish a laser safety program. Currently, the requirements and policies outlining laser safety programs for the U.S. Army are given in AR 11–9, AR 385–63, DA Pam 40–11, MIL–STD–1425A, and MIL–HDBK–828A. Product performance requirements for non-exempt lasers are given in 21 CFR 1040. The references cover many aspects and environments including manufacturing and production, range safety, and medical operations.

12–2. General requirements

a. Installation. Installations that operate Class 3b or Class 4 lasers should have a laser safety program. Management for each organization should assign an individual to serve as the LSO/RSO to be responsible for laser safety. The LSO/RSO requires this appointment from management to ensure users maintain safe practices with their equipment. Management may employ an LSO/RSO to oversee this responsibility while relying on technical input from an outside expert. The LSO/RSO may require special safety training, laser safety guidance documents, equipment, and support staff commensurate with the extent of his or her responsibilities. Each LSO/RSO, regardless of command level, should maintain a laser safety program with several key components. The key operational elements of a laser safety program are given in Table 12–1.

Table 12–1
Operational elements

Elements	Description
LSO	Specifically appointed to the office and with specific authority and duties.
Inventory	An inventory of Class 3b or Class 4 lasers should be maintained and current.
Training	A specific training program commensurate with potential hazards.
Medical surveillance	A medical surveillance program that identifies "at risk" personnel.
Documentation	An overall program philosophy and procedures including guidelines, SOPs, regulations, and points of contact.
Survey schedule	A periodic survey schedule should be implemented.
Program update	A periodic update and review of the overall laser safety program should be conducted.

b. LSO/RSO. The LSO/RSO is appointed in writing to set-up, manage, and enforce a laser safety program. The LSO/RSO training and experience requirements will be commensurate with the mission responsibilities and the overall installation or activity laser hazard level. The LSO/RSO determines and/or is responsible for the evaluation and control of laser hazards, including—

(1) Laser classifications.
(2) Hazard evaluations.
(3) Procedure and equipment approvals.
(4) Inventory, signs and labels.
(5) Safety features.
(6) Audits.
(7) Training.
(8) Medical surveillance.
(9) Accident reporting.
(10) Evaluation of laser treatment areas.
(11) Administrative and engineering control measures.
(12) Safety instructions.
(13) Documentation.
(14) Appropriate PPE, such as laser eye protective devices.

c. Inventory. An inventory of lasers should be maintained LSO/RSO. The inventory should include, at a minimum, ANSI Class 3b and Class 4 and FDA Class IIIb and Class IV laser systems. The inventory is a cornerstone to the laser safety program. The inventory should be updated from both the user level and from the logistics level. If a laser is newly acquired, modified, or the operating conditions change, the inventory mechanism should have the ability to capture the new information from the user level. If a laser is purchased, decommissioned, or transferred, the inventory mechanism should capture the new information from the logistics level. The laser inventory should, at a minimum, contain: laser source type with the laser parameters specified, manufacturer, model number, quantity, hazard class, wavelength, power and/or energy, mode (that is, CW or pulsed), location of the laser (with pertinent information such as room number and phone number), the primary user and/or point of contact for the laser, and any additional notes such as safety equipment required, other laser parameters (that is, divergence) or pertinent special operation notes. An accurate and up-to-date inventory will aid significantly in the implementation of an effective laser safety program.

d. Training. Training programs are a required part of a laser safety program. The mission and overall potential hazard level will dictate the need and degree of training for a training requirement or periodic training program. The training area should include general laser safety with the specific device because each situation can differ. Training can involve a required course or involve simple documentation distributed by the LSO/RSO to the user level. The LSO/RSO should have the ability to determine the type and frequency of training requirements.
(Note: The LSO/RSO should ensure medical maintenance personnel are trained and understand the hazards especially if they perform maintenance or service on the laser sources.)

e. Medical surveillance. Medical surveillance should be implemented according to current U.S. Army policy. The current U.S. Army policy is outlined in appendix C of this document. Typically, the Occupational Health Office administers the medical surveillance program. The LSO/RSO should have a mechanism in place to identify laser workers and to monitor the medical surveillance program.

f. Records and documentation. The laser safety program, in general, should be outlined in such written documentation as program philosophies, policies, and procedures including training, laser use, guidelines or SOPs, regulations, maintenance, service, and points of contact. The LSO/RSO should ensure that the necessary records required by applicable government and military regulations be maintained.

g. Survey schedule. The local LSO/RSO should perform a periodic survey schedule, as considered necessary, in all areas where laser equipment is used. The USACHPPM LORP is responsible for the periodic surveys of Army installations (that is, reviewing installation laser safety programs and providing recommendations for improving these programs).

h. Program update. The LSO/RSO should conduct a periodic update and review of the overall laser safety program.

12–3. Operational procedures

a. Laser locations. The LSO/RSO should know the locations of all laser equipment at his or her installation. The following examples are not all-inclusive and vary with organization:

(1) On an Army installation, hazardous lasers can be found in such areas as laser laboratories, storage areas for weapons, and equipment that use lasers, maintenance shops, ranges, and medical facilities.

(2) For a healthcare environment, hazardous lasers can be found in such fields as oral surgery; ophthalmology; dermatology; dental; gastroenterology; pathology; gynecology; ear, nose, and throat; and the operating room (generally, kept elsewhere and moved to the operating room when needed).

b. Hazard controls. The LSO/RSO should ensure that appropriate controls are in place. (See chapter 5 and 6 of this bulletin or ANSI Z136.1 for more detailed information.) There are two general methods to control the safe usage of laser equipment, which could pose potential hazards to personnel: engineering controls and administrative controls.

(1) Engineering controls are normally preferred, as they do not require an action from personnel. The LSO/RSO should ensure these controls work and are appropriate and should ensure the laser device itself is appropriately labeled. Examples of engineering controls include total beam enclosure, electrical door interlocks intended to disable the laser upon entry to an area, warning signs and/or lights with appropriate information and placement (for example, at entrance to laser areas with instructions concerning gaining entry to the area), and warning lights, which indicate that the laser is in operation. Often different engineering and administrative controls are needed for laser equipment service or maintenance.

(2) Administrative controls require personnel action, such as the following:

(a) Appointment of the LSO/RSO.

(b) Preparation and periodic review of safety instructions, safety guidelines, or SOPs.

(c) Posting of safety guidelines or SOPs near potentially harmful laser systems.

(d) Wearing laser eye protective devices when needed.

(3) The LSO/RSO should ensure laser eye protective devices are in place and not defective. For laser eye protectors, this includes appropriate labeling of OD and wavelength.

(4) The LSO/RSO should ensure the eye protectors are actually laser eye protectors. Guidelines or SOPs should be specific to the use and environment of the lasers and actually available to personnel that use the lasers. The safety guidelines or SOPs should clearly explain the potential hazards posed by the laser equipment, provide detailed control measures, and provide methods for reporting accidents or defective equipment. (Note: safety instructions provided by the laser system manufacturer are normally useful but may not provide enough information for completion of a safety guidelines or SOP.)

APPENDIX A

REFERENCES

Section I
Required Publications
Except as noted below, Army regulation and DA pamphlets are available online from the U.S. Army Publishing Directorate (APD) website: http://www.apd.army.mil/. Field manuals are available online from the APD (formerly the U.S. Army Publishing Agency (USAPA)) website: http://www.usapa.army.mil/. Technical bulletins, medical and USACHPPM technical guides are available online from the USACHPPM website: http://chppm-www-apgea.army.mil. DOD instructions are available online from the Washington Headquarters Services website: http://www.dtic.mil/whs/directives. Military Standards, Military Handbooks, and Standardization Agreements are available online at the Documentation Automation and Production Service (DAPS) website: http://assist.daps.dla.mil/. American National Standard Institute standards are available on line from the ANSI website: http://www.ansi.org/library/overview.aspx?menuid=11. Code of Federal Regulations are available online from the Government Printing Office website: http://www.gpoaccess.gov/CFR/index.html.

AR 10–5
Organization and Functions. (Cited in para 1–4a.)

AR 11–9
The Army Radiation Safety Program. (Cited in paras 1–4f, 1–4h, 3–5, 11–5c(1), 12–1b(2), and E–1.)

AR 40–10
Health Hazard Assessment Program in Support of the Army Materiel Acquisition Decision Process. (Cited in para 1–4d(3).)

AR 40–400
Patient Administration. (Cited in para 3–5.)

AR 385–10
Army Safety Program. (Cited in para 1–4g.)

AR 385–40
Army Accident Reporting and Records. (Cited in para 3–5).

TB MED 524

AR 385–63
Range Safety. (Cited in paras 1–4f, 1–4g, 1–4h, and 12–1b(2).)

DA Pam 40–11
Preventive Medicine. (Cited in paras 11–5c(1), and 12–1b(2).)

DA Pam 40–501
Hearing Conservation Program. (Cited in para 8–12.)

DA Pam 40–506
The Army Vision Conservation and Readiness Program. (Cited in para C–1b.)

FM 8–50
Prevention and Medical Management of Laser Injuries. (Cited in para H–2a.)

TB MED 523
Control of Hazards to Health from Microwave and Radio Frequency Radiation and Ultrasound. (Cited in para 8–6b.)

JP 3–09.1
Joint Tactics, Techniques, and Procedures for Laser Designation Operations (http://www.dtic.mil/doctrine//jel/new_pubs/jp3_09_1.pdf). (Cited in para 1–4h.)

MIL–HDBK–828A
Laser Safety on Ranges and in Other Outdoor Areas. (Cited in paras 1–1d, 1–1e, 1–4h, 6–2a, 6–11k, 12–1b(2), C–5a, and H–2a.)

MIL–STD–882D
System Safety. (Cited in paras 9–1b, 9–5j, and 10–2b.)

MIL–STD–1425A
Safety Design Requirements for Military Lasers and Associated Support Equipment. (Cited in paras 9–1a, 9–2b(1), 9–4, 9–5j, 10–4d, and 12-1b(2).)

21 CFR 1010.2
Certification. (Cited in para 9–5b.)

21 CFR 1010.5
Exemptions for products intended for United States Government use. (Cited in para 4–1e.)

21 CFR 1040
Performance Standards for Light-Emitting Products. (Cited in paras 9–5, 9–5n, and 12–1b(2).)

21 CFR 1040.10
Laser products. (Cited in para 11–1b.)

21 CFR 1040.11
Specific purpose laser products. (Cited in para 11–1b.)

29 CFR 1910.134
Respiratory protection. (Cited in para 8–5b(1)(b).)

ANSI Z136.1−2000
Safe Use of Lasers. (Cited in paras 10−1a, 11−2b, C−4, and C−5a.)

ANSI Z136.3−1996
Safe Use of Lasers in Health Care Facilities. (Cited in paras 11−1d, and C−4.)

Section II
Related Publications

FM 100−14
Risk Management

DODI 6055.11
Protection of DOD Personnel from Exposure to Radiofrequency Radiation and Military Exempt Lasers

MIL−HDBK−454
General Guidelines for Electronic Equipment

FAA Order 7400.2D
Procedures for Handling Airspace Matters, Part 8 Miscellaneous Procedures, Chapter 34 Outdoor Laser/High Intensity Light Demonstrations
(http://www.faa.gov)

Laser Notice No. 52
Guidance on the Department of Defense Exemption from the Food and Drug Administration (FDA) Performance Standard for Laser Products; Guidance for Industry and FDA. (Available from the U.S. Department of Health and Human Services, Food and Drug Administration, Center for Devices and Radiological Health
(http://www.fda.gov/cdrh/comp/guidance/1412.html.)

14 CFR 71
Designation of Class A, Class B, Class C, Class D, and Class E Aerospace Areas; Air Traffic Service Routes; and Reporting Points

TB MED 524

21 CFR Subchapter J
Radiological Health

29 CFR 1910
Occupational Safety and Health Administration, Department of Labor Standards

29 CFR 1910.101
Compressed gases (general requirements)

ACGIH
Threshold Limit Values (TLVs®) for Chemical Substances and Physical Agents, ACGIH, Cincinnati, OH, 2005. (TLV® is a registered trademark of the American Conference of Governmental Industrial Hygienists, Cincinnati, OH. Available at ACGIH, 1330 Kemper Meadow Drive, Cincinnati, OH 45240-1634.)

ANSI Z136.6−200
Safe Use of Lasers Outdoors

ANSI and Illuminating Engineering Society of North America (IESNA), RP–27.1–1996
Recommended Practice for Photobiological Safety for Lamps and Lamp Systems–General Requirements

ANSI and IESNA, RP–27.3–1996
Recommended Practice for Photobiological Safety for Lamps and Safety Systems–Risk Group Classification and Labeling

IEC 60825−1, edition 1.2 (2001-2008)
Safety of laser products - Part 1: Equipment classification, requirements and user's guide (http://domino.iec.ch/preview/info_iec60825-1%7Bed1.2%Den.pdf)

IEC 60825–2 (2004-2006)
Safety of laser products - Part 2: Safety of optical fiber communication systems (OFCS) (http://www.iec-normen.de/previewpdf/info_iec60825-2%7Bed3.0%7Den.pdf)

NFPA Code 30
Flammable and Combustible Liquids Code

NFPA Code 70
National Electrical Code (Article 500 - Hazardous (Classified) Locations) (http://ww.nfpa.org/aboutthecodes/)

NFPA Standard 45
Standard on Fire Protection for Laboratories Using Chemicals
(http://www.nfpa.org/aboutthecodes/)

STANAG–2900 ED.2(3)
Laser Radiation: Medical Surveillance and Evaluation of Over Exposure

STANAG–3606 ED.5
Evaluation and Control of Laser Hazards on Military Ranges

STANAG–3828 ED.1(9)
Minimum Requirements for Aircrew Protection Against the Hazards of Laser Target Designators

Section III
Prescribed Forms
This section contains no entries.

Section IV
Referenced forms
This section contains no entries.

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APPENDIX B

CALCULATIONS FOR HAZARD EVALUATION AND CLASSIFICATION

B–l. Introduction
As the eye is the structure most sensitive to damage from the laser beam in almost all cases, hazard evaluations based upon exposure limits for the eye can usually be applied to the rest of the body. Effects on the body by laser radiation depend highly on the wavelength or wavelengths of the laser. The wavelength of the laser could also be expressed in terms of frequency or energy per photon, but wavelength is the preferred unit to describe laser energy. Ultraviolet laser radiation can cause photochemical effects on the body similar to sunburn. Middle- and far-infrared laser energy can cause thermal burns. The most hazardous wavelength region for laser radiation is termed the retinal hazard region (400 nm–1400 nm) where the injury potential is to the retina rather than other parts of the body.

B–2. Definitions. Table B–1 provides the definition of the mathematical symbols used throughout appendix B.

Table B–1
Definitions of mathematical symbols

Symbols	**Definitions**
a	Diameter of emergent laser beam (cm)
α	Apparent angle subtended by a source at the location of the viewer (rad)
α_{max}	Apparent angle subtended by a source above which the thermal hazard is proportional to the radiance of the source (100 mrad)
α_{min}	Apparent angle subtended by a source above which extended source MPEs apply (1.5 mrad)
b	Major axis of elliptical cross-section beam (cm)
b_o	Diameter of laser beam incident on a focusing lens (cm)
b_1	Width of rectangular beam (cm)
c	Minor axis of elliptical cross-section beam (cm)
c_1	Height of rectangular beam (cm)
C_A	Wavelength correction factor (700 nm < λ < 1050 nm)
C_B	Wavelength correction factor (400 nm < λ < 600 nm)
C_C	Wavelength correction factor (1150 nm < λ < 1400 nm)
C_E	Extended source correction factor (table E–3)
C_p	Repetitive pulse correction factor ($n^{-0.25}$)
d_e	Diameter of the pupil of the eye (varies from approximately 0.2 to 0.7 cm)

Table B–1
Definitions of mathematical symbols (continued)

D	Barrier separation distance from the focal point of the final focusing lens (cm)
D_C	Diameter of collecting aperture of optical system (cm)
D_e	Diameter of the exit pupil of an optical system (cm)
D_{exit}	Exit port diameter of a laser (cm)
D_f	Limiting aperture from table E–5 (cm)
D_L	Diameter of laser beam at range *r* (cm)
D_m	Diameter of measurement aperture from table E-6 used for classification (cm)
D_o	Diameter of objective of an optical system (cm)
D_ρ	Diameter of reflected laser beam at reflecting surface (cm)
D_s	Barrier separation distance (direct beam) (cm)
D_{SD}	Diffuse reflection separation distance to barrier threshold limit (cm)
D_w	Diameter of a beam waist which could occur in front of the laser exit port (cm)
e	Base of natural logarithms, 2.718
f	Effective focal length of eye (1.7 cm)
f_0	Focal length of lens (cm)
F	PRF (s^{-1} or Hz)
F_{eff}	Effective (average) PRF (s^{-1})
G	Ratio of corneal irradiance or radiant exposure through magnifying optics to that received by the unaided eye
G_{eff}	Ratio of ocular hazard from optically aided viewing to unaided viewing
γ	Limiting field of view for MPEs based on photochemical hazards
H, E	Radiant exposure, (H) or irradiance (E) at range r, measured in $J \cdot cm^{-2}$ for pulsed lasers and $W \cdot cm^{-2}$ for CW lasers
H_o , E_o	Emergent beam radiant exposure (H_0) or irradiance (E_0) at the minimum measurement distance (10 cm) (units as for E, H)
H_{group}	Radiant exposure for the summation of all the energies in a group of pulses
H_p	The potential eye exposure, in the appropriate units, utilized in the determination of the optical density of protective eyewear
λ	Wavelength of source (nm)
L_e	Radiance of a source ($W \cdot cm^{-2} \cdot sr^{-1}$)
L_p	Integrated radiance of a source ($J \cdot cm^{-2}$ sr^{-1})
μJ	microJule
MPE	Maximum permissible exposure
MPE:E	MPE expressed as irradiance. For exposure to single pulses, the MPE is for peak power, and for a group of pulses, the MPE is for the average power ($W \cdot cm^{-2}$)
$MPE{:}H_{group}$	MPE expressed as radiant exposure for the summation of all the energy in a group of pulses ($J \cdot cm^{-2}$)
MPE:H	MPE expressed as radiant exposure for a single pulse or exposure ($J \cdot cm^{-2}$)
$MPE_{extended}$	MPE for an extended source
$MPE{:}L_P$	MPE expressed as integrated radiance ($J \cdot cm^{-2} \cdot sr^{-1}$)

Table B–1
Definitions of mathematical symbols (continued)

$MPE{:}L_e$	MPE expressed as radiance ($W \cdot cm^{-2} \cdot sr^{-1}$)
MPE/Pulse	MPE expressed as radiant exposure for each pulse in a pulse train ($J \cdot cm^{-2}$)
MPE_{skin}	MPE for skin exposure
MPE_{small}	MPE for a small source
MPE_{SP}	MPE expressed as radiant exposure for exposure to only one single pulse in a pulse train ($J \cdot cm^{-2}$)
NA	Numerical aperture of optical fiber
nJ	NanoJoule
P	Magnifying power of an optical system
ϕ	Emergent beam divergence measured in radians at the 1/e peak of irradiance points
ϕ_1	Emergent beam divergence of the major cross-sectional dimension of a rectangular or elliptical beam, measured in radians (rad)
ϕ_2	Emergent beam divergence of the minor cross-sectional dimension of a rectangular or elliptical beam, measured in radians (rad)
Φ	Radiant power (W)
Φ_0	Total radiant power output of a CW laser, or average radiant power of a repetitively pulsed laser, measured in watts (W)
Φ_d	Radiant power transmitted by an aperture (W)
Φ_{eff}	Power transmitted by the measurement aperture (see table E–6 for apertures)
Π	Pi
Q	Radiant energy (J)
Q_0	Total radiant energy output of a pulsed laser, measured in Joules (J)
Q_d	Radiant energy transmitted by an aperture (J)
Q_{eff}	Energy transmitted by the measurement aperture from table E–6 (J)
r	Range from to the viewer to the laser (cm)
r_{NHZ}	Nominal hazard zone
r_{NOHD}	The distance along the axis of the unobstructed beam from the laser beyond which the irradiance or radiant exposure is not expected to exceed the appropriate MPE (cm)
r_o	Distance from exit port to a beam waist formed in front of the laser (cm)
r_1	Range from laser target to the viewer (cm)
r_{1max}	Maximum from laser that there could be a correction to the MPE due to source size
R	Radius of curvature of a specular surface (cm)
ρ_λ	Spectral reflectance of a diffuse or a specular object at wavelength λ
S	Scan rate of a scanning laser (number of scans across the eye per second).
t	Duration of a single pulse or exposure (s)
t_{min}	Maximum duration for which the MPE (in $J\ cm^{-2}$) is the same as for 1 ns
T	Total exposure duration (in seconds) of a train of pulses
TL	Barrier threshold limit

Table B-1
Definitions of mathematical symbols (continued)

T_{max}	Total expected exposure duration; see limiting exposure duration
θ	Angle of incidence (equation 3)
θ_s	Maximum angular sweep of a scanning beam (rad)
θ_v	Viewing angle from the normal to a reflecting surface (figure B–5)
ω_0	Mode field diameter of single mode optical fiber (mm)

B–3. Viewing the primary beam (direct intrabeam viewing)

MPE values listed here are in terms of irradiance or radiant exposure incident on the body or cornea; however, in many cases, the actual hazard is to the retina due to concentration of the energy entering the eye and being focused on the retina by the cornea and lens of the eye. The worst possible situation would exist if the eye was focused at infinity and the beam concentrated at the retina in a diffraction-limited spot (wavelengths 400 nm–1400 nm).

B–4. Viewing the reflected beam

a. Specular reflection. Specular reflection requires a mirror-like surface. If the reflecting surface is fairly large and flat, the characteristics of the reflected beam may be considered identical to those of the direct beam except that the range is the sum of the distances from the laser source to reflector and from reflector to the eye. If the surface is not flat, the reflected energy arriving at the cornea is less and may be calculated for a uniformly curved surface if the curvature is known. Discounting finely polished mirrors, reflecting surfaces will generally reflect only a fraction of the beam. The magnitude of the reflection is dependent upon the specular reflectivity coefficient and the angle of incidence. For normal (perpendicular) incidence, typical plate glass will reflect approximately 8 percent and transparent plastics will reflect approximately 6 percent of the incident beam, but at near-grazing incidence, nearly all of the incident radiant energy is reflected. However, the beam tends to lose its collimation for grazing angles, depending on the size of the reflector. This effect is shown graphically in figures B–1 and B–2. The curves in figure B-1 show reflectance for light of polarization perpendicular (∟) to the plane of incidence and for light of polarization parallel (‖) to the plane of incidence. Such a curve drawn for water would show 2 percent reflection at normal incidence and a polarizing angle at 53 degrees. The practical significance of figure B–1 is shown in figure B–2 where a collimated laser beam is incident upon a plate glass window.

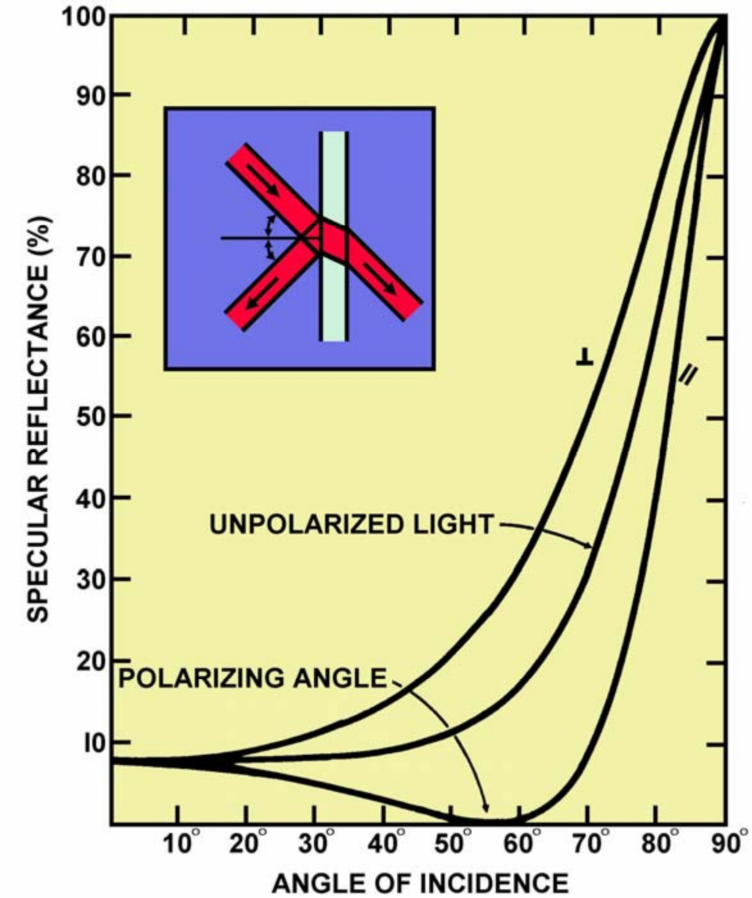

Figure B–1. Specular reflectance from both surfaces of plate glass having an index of refraction of 1.5

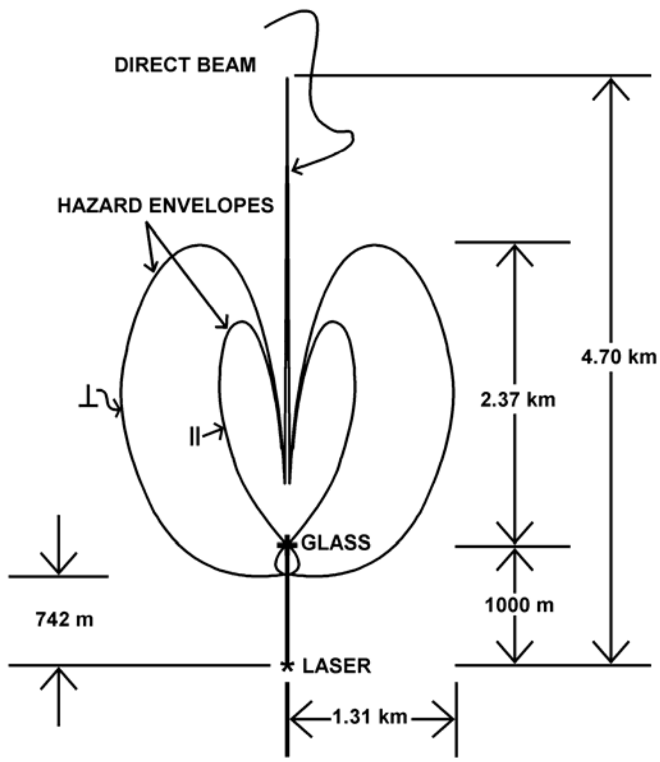

Figure B–2. Hazard envelopes created by a laser beam incident upon a vertically oriented flat (30 centimeter x 15 centimeter) glass surface

b. Diffuse reflection. The reflection from a flat diffuse surface obeys Lambert's Law (see equations 37 and 38), which relates the power or energy striking the diffuse surface to the corneal irradiance or radiant exposure of an observer viewing the surface at a particular distance away. Most of the time, the computed corneal irradiance or radiant exposure can be compared directly with published MPE values for small sources. However, when the diameter of the beam striking the surface is large and the distance from the surface to the observer is short, the assumption that the source is a small source is conservative and may overestimate the hazard.

(1) For less conservative assessment of the hazards incurred in the retinal hazard region (wavelengths between 400 nm and 1400 nm), both thermal and photochemical effects must be independently considered. In order to use extended-source thermal MPEs, the angular source size may be computed on axis by dividing the diameter of the laser beam striking the surface by the distance that the observer is away. The source will appear smaller if viewed off axis. If this angular source size α is larger than α_{min} (1.5 mrad), then a correction C_E may be made to the small-source MPE. The value of C_E is as follows:

$$C_E = \frac{\alpha}{\alpha_{\min}} \text{ for } \alpha \leq 100 \text{ mrad, and}$$

$$C_E = \frac{\alpha^2}{\alpha_{\min} \cdot \alpha_{\max}} \text{ for } \alpha > 100 \text{ mrad}$$

Where α_{max} is 100 mrad.

(2) For wavelengths between 400 nm and 600 nm, extended-source photochemical MPEs must also be considered, and either the thermal or photochemical MPE applies depending on which one indicates the most hazard. For exposure durations less than 10,000 s, the photochemical MPE is $100 \cdot C_B$ $J \cdot cm^{-2} \cdot sr^{-1}$ (integrated radiance) averaged over a cone angle γ, which is 11 mrad for exposures less than 100 s. Exposures from 10,000 s to 30,000 s are not more restrictive. The source radiance or integrated radiance is computed by dividing the corneal irradiance or radiant exposure by the source solid angle. The source solid angle Ω is given by—

$$\Omega = \frac{\pi \alpha^2}{4},$$

Where α is computed as described above.

(3) For exposure durations from 100 s to 10,000 s, γ is $1.1 \times \sqrt{t}$ mrad, and γ is 110 mrad for exposures up to 30,000 s.

c. Reflections from natural objects. Although most targets encountered in a field situation are reasonably diffuse, some may behave as specular or semi-specular reflectors and shall be evaluated. Natural surfaces, which provide some form of specular reflections, generally have a small radius of curvature (for example, water droplets, leaves) such that hazardous reflected levels exist only near the reflector. Still ponds and flat-plate glass are the principal reflectors that could produce hazardous reflections at a distance. As a general rule, laser irradiances or radiant exposures that are safe to view as diffuse reflections will not create hazardous reflections from water droplets and natural foliage at viewing distances greater than 1 m from the reflector. Many glossy surfaces behave in a specular manner at grazing angles of incidence; however, the reflected beam will be very close to the beam axis of the initial beam.

B–5. Other factors

a. Atmospheric effects. With the exception of beams directed up through the atmosphere, the effect of atmospheric attenuation may become a major factor in evaluating the radiant exposure or irradiance at distances greater than a few kilometers. Atmospheric attenuation should not be included for beams directed up through the atmosphere into outer space. This attenuation is the sum of three effects: Mie (or large particle) scattering, where the particle size is greater than the wavelength of the optical radiation and is normally the greatest contributor in the visible and near-infrared; Rayleigh (or molecular) scattering, where particle size is much less than the wavelength, is reasonably constant for a given wavelength, and is the greatest contributor in the ultraviolet; and absorption by gas molecules, which is normally relatively insignificant in comparison to scattering and may, therefore, be disregarded except in the infrared. Attenuation due to scattering is much more pronounced at shorter wavelengths; thus, red light from a ruby laser is scattered far less than wavelengths in the blue end of the visible spectrum. A clean atmosphere may, therefore, be expected to be relatively transparent to the ruby (694.3 nm) and Nd:YAG (1064 nm) wavelengths. The atmospheric attenuation effect upon a non-diverging beam is expressed by equations 21 and 22. The scattering effect may theoretically attenuate a ruby laser beam by as little as 10 percent at 10 km and 60 percent at 100 km, but such an atmospheric quality is rarely achieved even in arid zones. The meteorological visibility, based upon the entire visible spectrum, may not be readily utilized in arriving at the attenuation coefficient at a given wavelength. Atmospheric turbulence creates scintillation resulting in localized "hot spots" within the beam. Scintillation creates the largest variation in beam irradiances when the change of air temperature with height is great. The situation is most characteristic in a desert atmosphere with few clouds and least characteristic in a day with heavy overcast. A variation of local irradiances within a beam after traversing a beam path in excess of one kilometer may typically be a factor of 10 or more. Thus, local beam irradiances may occasionally exist, which are greater than would be expected if the beam experienced no turbulence.

b. The effect of optical viewing instruments.

(1) When viewing a bright object through a well-designed optical instrument, the amount of light or near-infrared radiation reaching the retina is increased by the square of the magnifying power of the system. For objects larger than a “point source,” there is a commensurate increase in the area of the retinal image; the retinal irradiance remains unchanged except for a slight reduction due to the loss or attenuation of light in the optical system.

(2) If, however, the laser were viewed directly from within the beam or by specular reflection, the parallel rays of the laser beam would behave as if they were coming from a point source. The retinal image, thus formed, may be diffraction-limited regardless of magnification by means of an optical viewing system. This means that the radiant power reaching the retina is increased by the square of the magnifying power of the optical system (except for light losses in the optical system) and that there would be a commensurate increase in the retinal irradiance.

(3) For some diode lasers, the size of the emitting source is large enough to qualify the laser as an extended-source laser. For these types of lasers, intrabeam viewing at close distances may result in an image on the retina larger than would be created by a point source. An increase in the MPE may be permitted under these limited viewing conditions.

B–6. Calculations for hazard evaluation and classification

Calculations are not necessary for hazard evaluation and classification in many applications; however, in range applications and other specialized uses where eye exposure is contemplated, several types of calculations permit the important quantitative study of potential hazards. Mathematical symbols used throughout are defined in paragraph B–6. Hazard classification and determination of exposure limits may require the use of equations in Section II. Equations useful in estimating exposure at significant distances from the laser and optically aided viewing are presented in Section III. Figures B–3 through B–5 illustrate ocular viewing conditions.

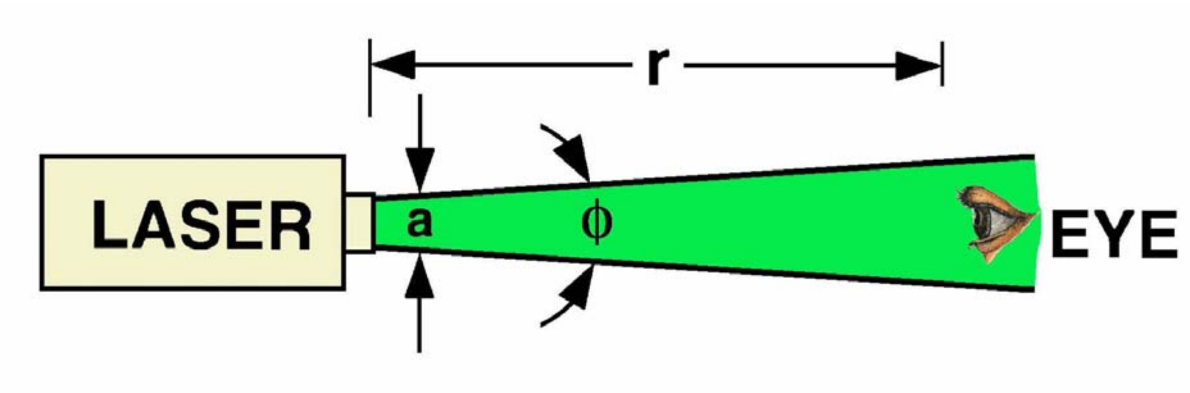

Figure B–3. Intrabeam viewing–direct beam (primary beam)

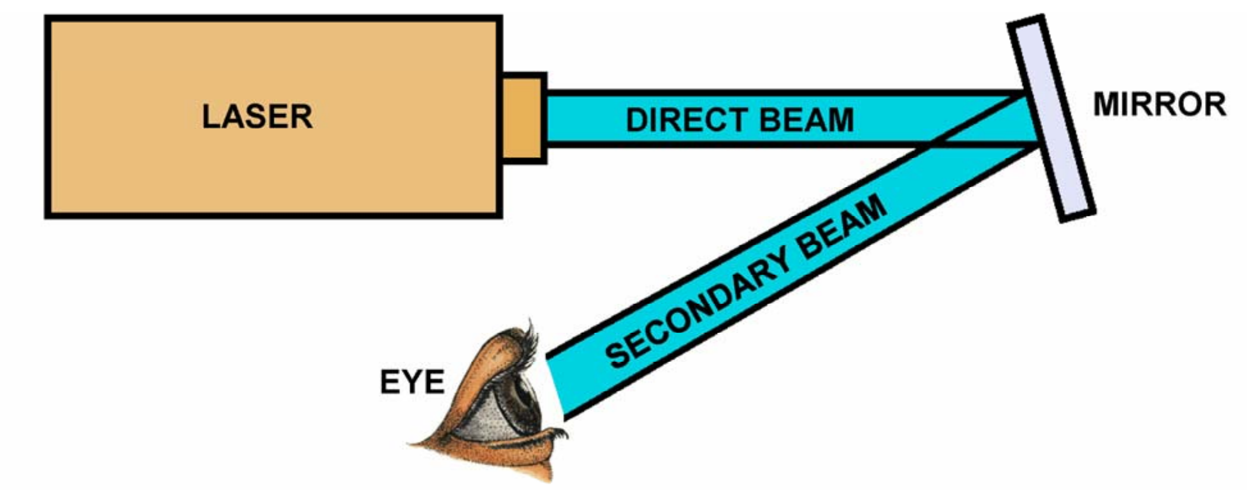

Figure B–4a. Intrabeam viewing–specularly reflected from flat surface (secondary beam)

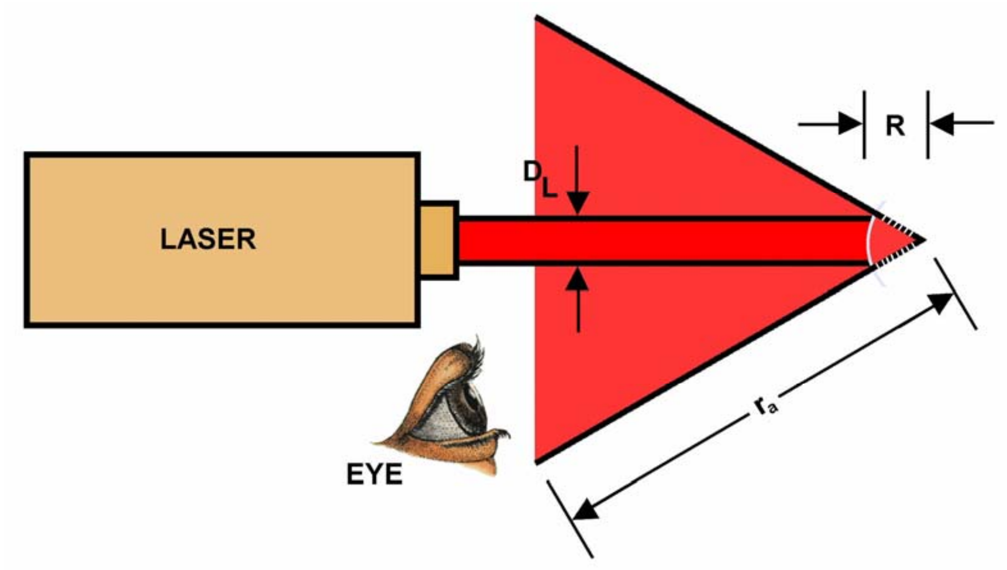

Figure B–4b. Intrabeam viewing-specularly reflected from curved surface (secondary beam)

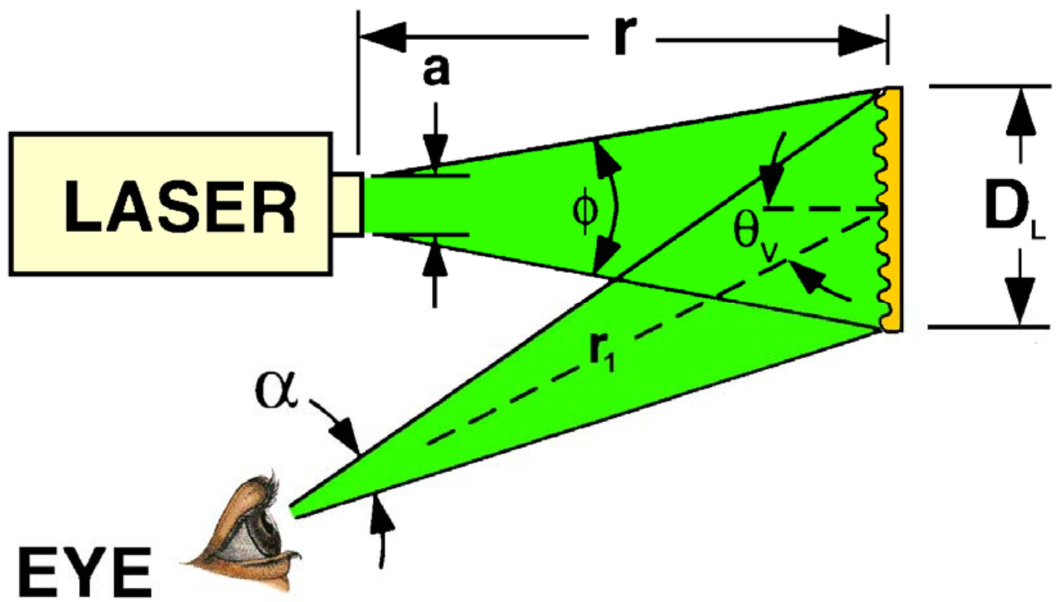

Figure B–5. Viewing a diffuse reflection-"r" represents the distance from the laser to the diffuse target, and r_1 represents the distance from the target to the eye

B–7. Maximum permissible exposure determination

Powerful or energetic lasers with wavelengths in the retinal hazard region (400 nm–1400 nm) can easily damage a person's vision since the cornea and lens focus the laser energy onto the retina. Direct intrabeam exposure of a collimated laser results in a small image on the retina no more than about 25 µm in diameter. The MPEs, expressed as corneal exposure, are very low in order to account for this natural focusing effect of the human eye. For retinal effects, the true hazard is related to the amount of laser power or energy that enters the pupil and is focused on the retina. Although infrared lasers (1400 nm–1 mm) do not present a retinal hazard, these lasers can still damage the eye with sufficient power or energy.

a. Determining the MPE for a single exposure. The MPE may be expressed in several different ways. In tables E–1 and E–2, the MPE is provided in either $J \cdot cm^{-2}$ or in $W \cdot cm^{-2}$. Usually, the MPE provided in tables E–1 and E–2 is expressed as radiant exposure ($J \cdot cm^{-2}$) for exposures lasting less than 10 s.

EXAMPLE 1. *Single–Pulse–Visible Laser.*

Determine the exposure limit (MPE) for a direct intrabeam exposure to a 694.3 nm ruby laser pulse having a duration of 8×10^{-4} s (0.8 ms). The exposure limit for such a laser exposure is defined in table E–1.

Solution. The MPE for visible lasers from table E–1 for wavelengths between 400 nm and 700 nm for exposure durations from 18 µs to 10 s is—

$$MPE : H = 1.8 t^{0.75} \cdot 10^{-3} \, J \cdot cm^{-2}$$

For a 0.8 ms exposure, the MPE is $1.8 \times (8 \times 10^{-4})^{0.75} \times 10^{-3}$ $J \cdot cm^{-2} = (1.8 \times 0.005 \times 10^{-3})$ $J \cdot cm^{-2} = 8.7 \times 10^{-6}$ $J \cdot cm^{-2} = 8.7$ $\mu J \cdot cm^{-2}$.

For a CW laser or for an exposure lasting several milliseconds, it is natural to express the MPE as irradiance (E) in $W \cdot cm^{-2}$. For a single exposure, the irradiance may be found by dividing the radiant exposure, H, by the exposure duration, T:

$$\text{Equation 1} \qquad \mathrm{E} = \frac{\mathrm{H}}{\mathrm{t}}$$

For a radiant exposure (H) of 8.7 microJoule (μJ)$\cdot cm^{-2}$ for 0.8 ms, the irradiance (E) is—

$$E = \frac{H}{t} = \frac{8.7 \ \mu\mathrm{J} \cdot \mathrm{cm}^{-2}}{0.8 \ \mathrm{ms}} = 1.09 \times 10^{-2} \ \mathrm{W} \cdot \mathrm{cm}^{-2} = 11 \ \mathrm{mW} \cdot \mathrm{cm}^{-2}$$

This is the peak irradiance since it represents the maximum irradiance that occurs during the pulse. Therefore, the MPE may be represented either as radiant exposure when it is provided in $J \cdot cm^{-2}$ or as irradiance when it is provided in $W \cdot cm^{-2}$.

EXAMPLE 2. *Single-Pulse, Near Infrared Laser.*

Determine the exposure limit for intrabeam direct viewing of a 1064 nm (Nd:YAG) laser having a pulse duration of 8×10^{-4} s.

Solution. Since the direct beam exposure limit for this laser listed in table E–1 is five times that for the visible laser having the same exposure duration—

$$H = 9 C_C t^{0.75} \cdot 10^{-3} \ \mathrm{J \cdot cm^{-2}}$$

The MPE is $9 \times (8 \times 10^{-4})^{0.75} \times 10^{-3}$ $J \cdot cm^{-2}$. (Note: C_C - table E–3 is 1 for 1064 nm). Therefore, the MPE is 4.35×10^{-5} $J \cdot cm^{-2}$ = 43.5 $\mu J \cdot cm^{-2}$.

b. Determining the MPE for a repetitively pulsed laser. The MPE for a pulsed laser is computed in the same way as for a CW laser. The exposure duration for the pulse is the pulse width. However, for repetitively pulsed lasers, exposure to many pulses is possible over an exposure duration of 10 or 100 s. The MPE is determined from three calculation methods (rules 1, 2, and 3). The MPE indicating the greatest hazard is the applicable MPE. The MPE for a single pulse during an exposure is limited to—

Rule 1: *Single Pulse Limit*. The MPE_{SP} for any single pulse during the exposure.

Rule 2: *Average Power Limit.* The MPE for the duration of all pulse trains (within the exposure duration) lasting for T seconds, divided by the number of pulses, n, during T, for all pulse train durations up to T_{max} (or T_2 if T_2 is smaller than T_{max}).

Rule 3: *Repetitive Pulse Limit*. The MPE for a single pulse within a pulse train multiplied by a correction factor C_P, i.e., $n^{-0.25}$, where n is the number of pulses that occur during an exposure duration T_{max}. For this rule, the MPE is based on a minimum pulse width of t_{min} and all pulses within t_{min} (18 μs for λ = 400 nm to 1050 nm and 50 μs for λ = 1050 nm to 1400 nm) are considered one pulse.

EXAMPLE 3. *Repetitively Pulsed Visible Laser-Very High PRF.*

Determine the direct intrabeam exposure limit of a 514.5 nm (argon) laser for a 0.25 s total exposure T, operating at a PRF = 10 megahertz (MHz) and t = 10 ns (i.e., 10^{-8} s).

Solution. Rule 2, average power limit will apply, since the PRF is greater than 55 kHz ($1/t_{min}$). However, all three rules will be tested.

Rule 1. *Single Pulse Limit*: The MPE for a single pulse lasting 10 ns at a wavelength of 514.5 nm can be found from table E–1. For pulse durations greater than 1 ns and less than 18 µs, for wavelengths from 400 nm to 700 nm, the MPE is 5.0×10^{-7} J·cm^{-2}.

$$MPE_{SP} = 0.5 \times 10^{-6} \text{ J·cm}^{-2}$$

Rule 2. *Average Power Limit*: For this case, *t* is 0.25 s exposure. The MPE using rule 2 is—

$$MPE{:}H_{group} = 1.8\ t^{0.75} \times 10^{-3} \text{ J·cm}^{-2}$$

$$= 1.8(.25)^{0.75} \times 10^{-3} \text{ J·cm}^{-2}$$

$$= 6.4 \times 10^{-4} \text{ J·cm}^{-2},$$

for all of the pulses in the 0.25 s train.

The total number of pulses (*n*) in the 0.25 s train is—

Equation 2 $$n = F_{eff} \times T$$

$= 10^7$ Hz × 0.25 s = 2.5×10^6 pulses. (The unit Hz is equivalent to 1/s).

Therefore, the MPE/pulse is—

$$\text{MPE/pulse} = \frac{6.4\times10^{-4}\ J \cdot cm^{-2}}{2.5\times10^{6}\ \ pulses}$$

$= 0.25$ nJ·cm^{-2}/pulse.

Since there are no special pulse codes emitted, no additional pulse train durations need to be considered.

Rule 3. *Repetitive Pulse Limit:* The *MPE/pulse* is the MPE_{SP} reduced by a repetitive pulse correction factor C_P (assuming that the pulse duration is greater than 1 ns; otherwise, a new MPE_{SP} needs to be calculated based on t_{min}). C_P is a function of the number of pulses to which a person could be exposed. Since multiple pulses are emitted within t_{min}, all the pulses within t_{min} would be considered as 1 pulse and the resulting PRF is limited to 55 kHz. Since no unusual code structure exists for this laser, rule 3 yields the same result as rule 2.

EXAMPLE 4. *Repetitively Pulsed, Near-Infrared Laser with Moderate PRF.*

Determine the intrabeam viewing exposure limit for a 905 nm (gallium arsenide) laser, which has a pulse width, *t*, of 100 ns (that is, 10^{-7} s) and a PRF of 1 kHz.

Solution. Since the 905 nm wavelength will not provide a natural aversion response as a visible wavelength laser would, assume a 10-s exposure duration *T*, for this particular laser application where eye and body movements limit the exposure duration. All three rules must be tested since the PRF of this laser is below the critical frequency (55 kHz).

Rule 1. *Single Pulse Limit.* From table E–3, the wavelength correction factor, C_A, is 2.57 at 905 nm.

$$MPE_{SP} = 5.0\ C_A \times 10^{-7}\ \text{J·cm}^{-2}$$

$$= 1.29 \times 10^{-6}\ \text{J·cm}^{-2}.$$

Rule 2. *Average Power Limit.* For the entire 10 s exposure, the MPE is—

$$MPE{:}H_{group} = 1.8\ C_A\ t^{0.75} \times 10^{-3}\ \text{J·cm}^{-2}.$$

The total number of pulses emitted during a 10 s exposure is—

$$n = 1\ \text{kHz} \times 10\ \text{s} = 10{,}000\ \text{pulses}.$$

The *MPE/pulse* for a 10 s exposure (*t*) is—

$$MPE\,/\,pulse = \frac{1.8 \cdot C_A \cdot t^{0.75} \times 10^{-3}\ \text{J} \cdot \text{cm}^{-2}}{10^4\ \text{pulses}}$$

$$= 2.6 \times 10^{-6}\ \text{J·cm}^{-2}.$$

Rule 3. *Repetitive Pulse Limit.*

$$MPE/pulse = n^{-0.25} \times MPE_{SP}$$

$$= 10{,}000^{-0.25} \times (1.29 \times 10^{-6})\ \text{J·cm}^{-2}$$

$$= 1.3 \times 10^{-7}\ \text{J·cm}^{-2}.$$

Rule 3 provides the most conservative (lowest) MPE calculation. The MPE expressed as a cumulative exposure for the duration of the entire pulse train is—

$$MPE{:}H_{group} = T \times \mathrm{F} \times MPE/pulse$$

$$= (10\ \mathrm{s})(10^3\ \mathrm{Hz})(1.3 \times 10^{-7}\ \mathrm{J{\cdot}cm^{-2}})$$

$$= 1.3 \times 10^{-3}\ \mathrm{J{\cdot}cm^{-2}}.$$

This MPE may also be expressed in terms of average irradiance.

$$MPE : E = \frac{MPE : H_{group}}{T} = \frac{1.3 \times 10^{-3}\ \mathrm{J \cdot cm^{-2}}}{10\ \mathrm{s}}$$

$$= 1.3 \times 10^{-4}\ \mathrm{W{\cdot}cm^{-2}}.$$

EXAMPLE 5. *Low PRF, Long Pulse, Repetitively Pulsed Visible Laser.*
Determine the exposure limit for a 632.8 nm (helium-neon) laser where T_{max} = 0.25 s, pulse width, $t = 10^{-3}$ s, and F = 100 Hz.

Solution. Since the PRF of the laser is much less than 55 kHz, the pulse width exceeds 1 ns, the exposure duration is 0.25 s, and the pulses are evenly spaced, rule 3 is the appropriate method to follow. All three rules will be tested.

Rule 1. *Single Pulse Limit:* The MPE for a single 1 ms pulse at the 632.8 nm wavelength from table E–1 is—

$$MPE_{SP} = 1.8\ t^{0.75} \times 10^{-3}\ \mathrm{J{\cdot}cm^{-2}}$$

$$= 1.8 \times 0.001^{0.75} \times 10^{-3}\ \mathrm{J{\cdot}cm^{-2}}$$

$$= 1.01 \times 10^{-5}\ \mathrm{J{\cdot}cm^{-2}}.$$

The MPE in terms of average power for rule 1 is—

$$MPE{:}E = MPE/pulse \times F$$

$$= 1.01 \mathrm{\ x\ } 10^{-5}\ \mathrm{J{\cdot}cm^{-2}} \mathrm{\ x\ } 100\ \mathrm{Hz}$$

$$= 1 \mathrm{\ x\ } 10^{-3}\ \mathrm{W{\cdot}cm^{-2}} = 1\ \mathrm{mW{\cdot}cm^{-2}}.$$

Rule 2. *Average-Power Rule*. The MPE using rule 2 is—

$$MPE:H_{group} = 1.8\ t^{0.75} \times 10^{-3}\ J \cdot cm^{-}2$$

$$= 1.8 \times (0.25)^{0.75} \times 10^{-3}\ J \cdot cm^{-2}$$

$$= 6.4 \times 10^{-4}\ J \cdot cm^{-2}$$

The MPE may be expressed in terms of average power

$$MPE : E = \frac{MPE : H_{group}}{T} = \frac{6.4 \times 10^{-4}\ \mathrm{J \cdot cm^{-2}}}{0.25\ \mathrm{s}}$$

$$= 2.55 \times 10\text{-}^{3}\ W \cdot cm^{-2}$$

The number of pulses in a 0.25 s exposure is n = F× T = 25 pulses. Therefore, the MPE/pulse for rule 2 is—

$$\frac{H_{group}}{n} = \frac{6.4 \times 10^{-4}\ \mathrm{J \cdot cm^{-2}}}{25} = 2.56 \times 10^{-5}\ \mathrm{J \cdot cm^{-2}/pulse}$$

Rule 3. *Repetitive Pulse Limit*.

$C_P = (n)^{-0.25} = (25)^{-0.25} = 0.45$. The *MPE/pulse* is obtained by multiplying the MPE_{SP} by C_P.

$$MPE/pulse = C_P \times MPE_{SP}\ J \cdot cm^{-2}$$

$$= (0.45)(1.01 \times 10\text{-}^{5})\ J \cdot cm^{-2}$$

$$= 4.55 \times 10^{-6}\ J \cdot cm^{-2}.$$

The most restrictive MPE/pulse is 4.55 µJ·cm^{-2} (rule 3) and should, therefore, be used. In terms of average power, this MPE is 0.45 mW·cm^{-2}.

EXAMPLE 6. *One-Pulse Group, Short-Pulse Laser.*

Find the exposure limit of a Q-switched Nd:YAG laser (1064 nm) that has an output of three, 20-ns pulses each separated by 100 ns.

Solution. This is not a repetitively pulsed laser in the usual sense, that is, one having a continuous train of pulses lasting of the order of 0.25 s or more with the pulses being reasonably equally spaced.

Rule 1. *Single-Pulse Limit.* The MPE for a single 20-ns pulse at the 1064 nm wavelength as found in table E-1 is—

$$MPE_{SP} = 5.0\ C_C \times 10^{-6}\ \text{J}\cdot\text{cm}^{-2}.$$

The correction factor C_c, found in table E-3, has a value of 1.0 at 1064 nm. Therefore, the MPE is—

$$MPE_{SP} = 5 \times 10^{-6}\ \text{J}\cdot\text{cm}^{-2}.$$

Rule 2. *Average-Power Rule.* The average power MPE is calculated for a pulse train of duration, *T*, of 220 ns (total time for the 3 pulses plus the time between pulses), which is less than t_{min} of 50 µs.

$$MPE{:}H_{group} = 5 \times 10^{-6}\ \text{J}\cdot\text{cm}^{-2} \text{ for the 3 pulses}$$

$$MPE\,/\,pulse = \frac{5 \times 10^{-6}\ \text{J}\cdot\text{cm}^{-2}}{3\,\text{pulses}}$$

$$= 1.67\ \mu\text{J}\cdot\text{cm}^{-2}/\text{pulse}.$$

Rule 3. *Repetitive Pulse Limit.* Since the train duration, *T*, is less than t_{min}, all of the pulses are considered as 1 pulse, and the energies are summed. Consequently, C_P is 1.0. The MPE based on t_{min} is 5×10^{-6} J·cm^{-2} for the sum of the energies of all three pulses. Therefore, the *MPE/pulse* based on rule 3 is the same as rule 2 (1.67 µJ·cm^{-2}).

EXAMPLE 7. *Series of Pulse Groups, Short-Pulse Laser*.

Find the exposure limit for a doubled Nd:YAG laser (532 nm) used in a pulse-coded signal transmitter. The laser presents 100 words to transmit a message. Each word lasts 0.4 ms and contains 10 laser pulses of 20-ns duration randomly spaced. The words are transmitted every 1 ms for a total message length of 100 ms.

Solution.

Rule 1. *Single-Pulse Limit*. The MPE_{SP} for a 20 ns pulse can be found in table E–1.

$$MPE_{SP} = 5 \times 10^{-7}\ \text{J}\cdot\text{cm}^{-2}.$$

Rule 2. *Average-Power Rule*. A number of calculations are required for this method since the pulses are in groups. First, consider one word, a group of 10 pulses that last 0.4 ms.

$$MPE: H_{group} = 1.8 \cdot t^{0.75} \times 10^{-3}\, \mathrm{J \cdot cm^{-2}},\ (t = 0.4\ \mathrm{ms})$$

$$= 5.1 \times 10^{-6}\ \mathrm{J \cdot cm^{-2}}.$$

The *MPE/pulse* is then—

$$MPE / pulse = \frac{5.1 \times 10^{-6}\ \mathrm{J \cdot cm^{-2}}}{10} = 5.1 \times 10^{-7}\ \mathrm{J \cdot cm^{-2}}$$

Second, calculate the MPE for the entire message length of 100 ms. The MPE for 100 ms from table E–1 is—

$$MPE: H_{group} = 1.8 \cdot t^{0.75} \times 10^{-3}\, \mathrm{J \cdot cm^{-2}}$$

$$= 3.2 \times 10^{-4}\ \mathrm{J \cdot cm^{-2}}$$

The MPE is for all of the pulses contained within 100 ms. The number of pulses during this time is—

$$n = 100\ \text{words/message} \times 10\ \text{pulses/word} = 1000\ \text{pulses}$$

The *MPE/pulse* is then—

$$MPE / pulse = \frac{3.2 \times 10^{-4}\ \mathrm{J \cdot cm^{-2}}}{1000} = 3.2 \times 10^{-7}\ \mathrm{J \cdot cm^{-2}}$$

Since the second result is less than the previous, the *MPE/pulse* for rule 2 is 3.2×10^{-7} J·cm^{-2}.

Rule 3. *Repetitive Pulse Limit.* The MPE_{SP} is 5×10^{-7} J·cm^{-2} and C_P is $1000^{-0.25} = 0.178$. Therefore, the *MPE/pulse* is 8.9×10^{-8} J·cm^{-2}, which is the applicable MPE since it is the lowest.

EXAMPLE 8. *Repetitively Pulsed Pulse Groups.*

Find the exposure limit for an argon laser (514.5 nm) used in a pulse-code-modulated (PCM) communications link. The laser presents 10^4 "words" per second (that is, 10^4 pulse groups per second) and each word consists of five 20-ns pulses spaced at coded intervals such that each pulse group lasts no longer than 1 μs.

Solution. The effective PRF (F_{eff}) of the transmitter is determined by multiplying the number of pulses per word by the number of words per second.

$$F_{eff} = 5\,\frac{\text{pulses}}{\text{word}} \times 10^4\,\frac{\text{words}}{\text{s}} = 50\ \text{kHz}$$

Rule 1. *Single-Pulse Limit.* The MPE_{SP} for a 20 ns pulse can be found in table E–1.

$$MPE_{SP} = 5 \times 10^{-7}\ \text{J·cm}^{-2}.$$

Rule 2. *Average-Power Rule.* A number of calculations are required for this method since the pulses are in groups. First, consider one word, a group of 5 pulses that last 1 µs.

$$MPE{:}H_{group} = 5 \times 10^{-7}\ \text{J·cm}^{-2}.$$

The *MPE/pulse* is then—

$$MPE\,/\,pulse = \frac{5\times10^{-7}\ \text{J}\cdot\text{cm}^{-2}}{5} = 1.0\times10^{-7}\ \text{J}\cdot\text{cm}^{-2}$$

Second, calculate a 0.25 s exposure. The MPE for a 0.25 s (momentary exposure) from table E–1 is—

$$MPE : H_{group} = 1.8\cdot t^{0.75}\times10^{-3}\,\text{J}\cdot\text{cm}^{-2}$$

$$= 6.36\times10^{-4}\,\text{J}\cdot\text{cm}^{-2}$$

The MPE is for all of the pulses contained within 0.25 s. The number of pulses during this time is—

$$n = F_{eff}\times T = 1.25\times10^{4}\ \text{pulses}$$

The *MPE/pulse* is then—

$$MPE\,/\,pulse = \frac{6.36\times10^{-4}\,\text{J}\cdot\text{cm}^{-2}}{1.25\times10^{4}\ \text{pulses}}$$

$$= 5.09\times10^{-8}\ \text{J}\cdot\text{cm}^{-2}$$

Since the second result is less than the previous, the *MPE/pulse* for rule 2 is 5.09×10^{-8} J·cm^{-2}.

Rule 3. *Repetitive Pulse Limit.* The MPE for a single pulse based on t_{min} (18 µs for visible lasers) is—

$$MPE{:}H = 5 \times 10^{-7}\ \text{J·cm}^{-2}.$$

All pulses occurring within t_{min} are considered a single pulse. Pulse groups for this PCM communications link are 1 µs in duration; therefore, an entire pulse group occurs within t_{min}. The number of pulse groups contained within t_{min} is—

$$\text{Words } (t_{min}) = \text{Group Frequency} \times t_{min}$$

$$= 10{,}000\,\frac{\text{words}}{\text{s}} \times 18 \times 10^{-6}\ \text{s} = 0.18\ \text{word}$$

No more than one pulse group is contained within t_{min}. The number of pulses (words) separated by a time at least as long as t_{min} for a 0.25 s exposure duration is—

$$n(\text{words}) = 10{,}000\ \text{words/s} \times 0.25\ \text{s}$$

$$= 2.5 \times 10^{3}$$

$$C_P = n^{-0.25} = (2.5 \times 10^{3})^{-0.25} = 0.141$$

$$MPE / word = 5 \times 10^{-7} \times C_P\ \text{J} \cdot \text{cm}^{-2}$$

$$= 7.07 \times 10^{-8}\ \text{J·cm}^{-2}.$$

Since there are 5 pulses per word, the *MPE/pulse* is—

$$MPE / pulse = \frac{MPE / word}{pulses / word}$$

$$= \frac{7.07 \times 10^{-8}\ \text{J} \cdot \text{cm}^{-2}}{5\ \text{pulses}} = 1.41 \times 10^{-8}\ \text{J} \cdot \text{cm}^{-2}$$

Of the three rules, rule 3 provides the most conservative MPE. The *MPE/pulse* for this example is 1.4×10^{-8} J·cm^{-2}.

EXAMPLE 9. *UV Laser, Dual Limits.*

An argon fluoride excimer laser operating at 193 nm is used in the operating room for corneal sculpting. The laser operates at a PRF of 400 Hz and each pulse is 20 ns in length. Considering all three rules, what is the lowest exposure limit for this laser, for a 10-s exposure duration?

Solution. The MPEs for UV lasers ($\lambda < 400$ nm) are based on both thermal effects and photochemical effects. Therefore, dual limits must be considered when determining the most restrictive MPE for these types of lasers. The MPE, based on photochemical effects on the eye or skin, for 193 nm laser radiation is 3 milliJoule (mJ)·cm^{-2} for exposure durations lasting 1 ns to 30 ks. The thermal MPE for this wavelength, 0.56 $t^{0.25}$, also can't be exceeded. The MPE can be computed by applying all three rules for both photochemical and thermal effects.

Rule 1. *Single-Pulse Limit.* For this laser, the thermal MPE limit for exposure to a single pulse is—

$$MPE_{SP} = 0.56 \cdot t^{0.25}\,\mathrm{J \cdot cm^{-2}} = 0.56 \times (20 \times 10^{-9})^{0.25}\,\mathrm{J \cdot cm^{-2}} = 6.66\ \mathrm{mJ \cdot cm^{-2}}$$

For the photochemical limit, the MPE is the same as for the entire exposure (3 mJ·cm^{-2}) Therefore, the MPE for rule 1 is based on the photochemical limit.

$$MPE_{SP}\ \text{(Rule 1)} = 3\ \mathrm{mJ \cdot cm^{-2}}.$$

Rule 2. *Average-Power Rule.* For thermal effects, the MPE is—

$$Thermal\ MPE : H_{group} = 0.56 \cdot t^{0.25}\ \mathrm{J \cdot cm^{-2}}$$

Where t is now the total duration of the exposure, T_{max}, which is 10 s.

$$= 0.56 \times 1.78\ \mathrm{J \cdot cm^{-2}} = 1.0\ \mathrm{J \cdot cm^{-2}}$$

In a 10-s exposure, an individual could be exposed to 400 × 10 = 4000 pulses. The thermal MPE for each pulse is then—

$$\frac{Thermal\ MPE}{pulse} = \frac{1.0\ \mathrm{J \cdot cm^{-2}}}{4 \times 10^{3}\ \text{pulses}}$$

$$= 2.5 \times 10^{-4}\ \mathrm{J \cdot cm^{-2}/pulse}$$

The MPE based on photochemical effects for an accumulated exposure over a 10-s duration is 3 mJ·cm^{-2}. Therefore the *MPE/pulse* based on photochemical effects is—

$$\frac{Photochemical\ MPE}{pulse} = \frac{3.0 \times 10^{-3}\ \mathrm{J \cdot cm^{-2}}}{4 \times 10^{3}\ \text{pulses}}$$

$$= 7.5 \times 10^{-7}\ \mathrm{J \cdot cm^{-2}/pulse}$$

Since the photochemical MPE is less than the thermal MPE for rule 2, the MPE for rule 2 is—

$$MPE\,/\,pulse = 7.5 \times 10^{-7}\ \mathrm{J \cdot cm^{-2}}$$

Rule 3. *Repetitive Pulse Limit.* To compute the MPE according to rule 3, the repetitive-pulse correction factor is applied to the thermal MPE_{SP} but not to the photochemical limit because rule 3 protects against sub-threshold pulse cumulative thermal injury. The thermal MPE_{SP} is 6.66 mJ·cm^{-2}. The exposure to 4000 pulses is possible. The value of C_P, $n^{-0.25}$, is 0.126.

The *MPE/pulse* for rule 3 is—

$$MPE\,/\,pulse = 6.66 \times 10^{-3}\ \mathrm{J \cdot cm^{-2}} \times 0.126 = 8.4 \times 10^{-4}\ \mathrm{J \cdot cm^{-2}}$$

Comparing the MPEs, both thermal and photochemical for all three rules, the photochemical MPE for rule 2 yields the lowest *MPE/pulse* of 0.75 μJ·cm^{-2} or an average irradiance of 0.3 mW·cm^{-2}.

c. Determining the MPE for Extended Sources. Most lasers have a small source, $\alpha \leq$ 1.5 mrad, but lasers that are formed by combining a laser diode with a collimating lens or by re-collimation of diffuse laser energy may have a larger source size when viewed at a close distance. For extended source lasers, the physical source size cannot exceed the diameter of the laser exit port aperture. The angular source size of these lasers is limited to no more than the divergence of the beam. Extended source MPEs are generally applied to diffuse reflections and then only to the retinal hazard region (400 nm–1400 nm). When viewing diffuse reflections, the angle, α_{min}, is used to determine if the extended-source MPE applies. Figure B–5 shows the relationship between D_L, a, and r_1.

Equation 3 $$\alpha = \frac{D_L \cdot \cos\theta_\upsilon}{r_1}, \text{ for } \theta_\upsilon \leq 0.37 \text{ radian}$$

Equation 4 $$\alpha_{\min} = \frac{D_L \cdot \cos\theta_\upsilon}{r_{1_{\max}}}$$

EXAMPLE 10. *MPE for Extended Sources.*

Find the extended-source MPE for a gallium arsenide (904 nm), diode laser, used in a MILES training laser, operating at 2.73 kHz and having a pulse width of 200 ns. The beam is circular, and its diameter at the exit port is 1.5 cm. The collimating lens (exit aperture) is 3 cm in diameter. The source size appears to be 4.5 mrad within a distance of about 6 m from the exit aperture. Find the MPE for this laser at a distance of 10 cm from the exit aperture.

Solution. Although most lasers have a small source, lasers created by a laser diode and collimating lens or by re-collimation of diffused laser energy can have a source size larger than

α_{min} when viewed at a close distance. These lasers are extended sources. The source size cannot exceed the divergence of the beam. In addition, the physical source size cannot exceed the diameter of the laser exit aperture. The source size is a parameter only obtained through measurement. Beyond 667 cm, the source size is limited by the laser exit port, and a lower MPE applies.

$$Source\ Size = \frac{3\,cm}{667\,cm} = 4.5\,mrad$$

The small source MPE, calculated from rule 3, for this laser is—

$$(MPE/pulse)_{small} = MPE_{SP} \times C_P \ \mathrm{J \cdot cm^{-2}}$$

The number of pulses used to calculate C_P is determined from T_2 if an exposure duration, T_{max}, is not specified. T_2 is based on the source size and is contained in table E–3.

$$T_2 = 10 \times 10^{\frac{(\alpha - 0.0015)}{0.0985}} = 10 \times 10^{\frac{(0.0045 - 0.0015)}{0.0985}} = 10.73\,\mathrm{s}$$

The MPE_{SP} obtained from table E–1 is 1.28×10^{-6} $\mathrm{J \cdot cm^{-2}}$. The number of pulses that the laser would emit in 10.73 s is 29,293 resulting in a C_P value of 0.076. The MPE is then—

$$(MPE/pulse)_{small} = 1.28 \times 10^{-6}\ \mathrm{J \cdot cm^{-2}} \times C_P = 9.78 \times 10^{-8}\ \mathrm{J \cdot cm^{-2}}.$$

The extended-source MPE for this laser is obtained from the angular source size and the small-source MPE. The small-source MPE is multiplied by the correction factor C_E if the source subtends an angle greater than 1.5 mrad. From table E–3, for sources smaller than 100 mrad, C_E is the ratio of the angular subtense to 1.5 mrad. At the evaluation distance of 10 cm, the source subtends an angle of 4.5 mrad.

$$C_E = \frac{\alpha}{\alpha_{\min}} = \frac{4\,\mathrm{mrad}}{1.5\,\mathrm{mrad}} = 3.$$

The extended-source MPE is—

$$(MPE/pulse)_{extended} = (MPE/pulse)_{small} \times C_E = 2.94 \times 10^{-7}\ \mathrm{J \cdot cm^{-2}}$$

d. Determining the MPE for a more complex repetitively pulsed laser. Laser systems continue to be more complex in nature combining several evaluation methods for one system. For instance a laser may be an extended source and emit pulse groups of both high and low frequency. Sometimes the pulses in these groups are counted singly and other times several pulses are combined into one big group for evaluation. Sometimes, these complex beams form an even more complicated scanning pattern so that the individual pulses are not the same intensity. Three rules have been given for evaluating repetitively pulsed lasers, either as a constant pattern or in pulse groups. However, exposure to groups of pulses of varying intensity is becoming more common, and extremely complicated pulse structures may develop before a revision of this technical bulletin is issued. It is important to understand some principles of laser exposure in order to formulate MPE limits for future systems where the parameters do not fit into the confines of this section. It is also important to note that the laser safety exposure limits have changed very little since a comprehensive list of limits was first printed in 1973 in the first issue of ANSI Z136. The human body is known to have two biological responses to optical radiation—

(1) *Thermal and photochemical*. Either effect can determine the MPE. For ocular exposure or skin exposure to ultraviolet, these limits are listed in table E–1 or table E–4 (the limits are essentially the same). However, there is a thermal limit listed on the right hand side of the tables, which must not be exceeded as well ($0.56t^{0.25}$ J cm^{-2}).

(2) *Retinal hazards*. For the retinal hazard region, the photochemical limit is 100 C_B J cm^{-2}·steradian $(sr)^{-2}$. For blue and green wavelengths, the photochemical MPE produces a lower exposure limit after a few seconds of exposure than the thermal limit. In a medical setting, where normal response functions to bright light have been disabled for a patient, the photochemical MPE limit should be reduced by a factor of 5.

(3) *Thermal hazards*. Very short pulses produce a more pronounced effect than longer exposures. For pulses that are nanoseconds to microseconds long, there is a thermal confinement region, where the retinal MPE remains constant (this value, (t_{min}) is 18 µs for wavelengths between 400 nm and 1050 nm and 50 µs for wavelengths between 1050 nm–1400 nm). The same MPE applies for the combination of all energy received during these exposure durations. The retinal MPE is written in terms of corneal exposure (J cm^{-2}) with the assumption that the energy entering the cornea will be focused to a very small spot on the retina, usually no more than 25 µm in diameter. Continued exposure to the retina after a few seconds does not produce more damage to the retina from thermal effects than from a 10-s exposure.

(4) *Extended sources*. Extended sources of laser energy (usually diffuse reflections from lasers with a large beam diameter) must be evaluated with different MPEs than direct corneal exposure from collimated laser beams. Diffuse reflections of laser light more closely resemble exposure from other optical sources and, therefore, should not be penalized by directly applying exposure limits for direct exposure to collimated laser energy. Therefore, a correction factor is provided for intermediate size sources (currently between 1.5 mrad and 100 mrad angular subtense, but these values may change). The MPE is based on radiance (that is, brightness of the source) for larger sources (that is, larger than 100 mrad angular subtense).

(5) *Exposure to multiple pulses*. Exposure to multiple pulses of laser energy is generally more hazardous than exposure to a CW laser with the same average power. Determining how much more hazardous can, at times, be difficult. Three rules have been established for determining the repetitive correction factor. These three rules are: the MPE cannot be larger than it is for a single pulse, the MPE cannot be larger than it is for an equivalent CW laser, and that a reduction factor should be applied for exposure to multiple pulses. However, for lasers with pulses of varying intensity or for a laser that produces a raster scan on the retina with either a CW or pulsed laser, these rules are inadequate for determining an actual maximum permissible exposure limit.

(6) *Exposure to pulses of varying intensity*. There are two acceptable methods for determining a correction factor for repeated exposures of visible or infrared energy to the retina. One is based on the number of pulses received into the eye, and the other is based on the total "on" duration of the laser. The later can only be applied to retinal exposure accurately for pulses that are longer than t_{min}. For these longer pulses, which are not often produced by modern military lasers, the two methods are equivalent.

(7) *Varying-pulse-energy method*. A combination of these two equivalent accepted methods can be used to determine the MPE to pulses that are shorter than t_{min}, but vary in energy and/or pulse width. First, the magnitude of the pulse with maximum energy output is determined. Assuming that the duration of that pulse is less than t_{min}, then the duration of t_{min} is used for the width of that pulse. All other pulses occurring within an exposure duration of 10 s, and with a lesser (or same) pulse energy are assigned a width corresponding to the percentage of the energy of the maximum energy pulse multiplied by t_{min}. The combination of these widths is then used to determine an MPE from table E–1 for exposure durations from t_{min} to 10 s. This MPE will be somewhat larger than it is for t_{min}. The energies of all the pulses are then combined and compared to the calculated MPE. This ratio between pulse energy and MPE can then be used to determine optical density requirements or for determining NOHD.

B–8. Laser classification

a. Based on the potential for a laser to exceed the MPE, the classification of a laser is dependent on whether the laser is likely to be used in conjunction with optically aided viewing instruments (that is, 7×50 mm binoculars) or strictly unaided viewing. A laser's hazard classification is also based on the energy transmitted by the appropriate limiting aperture for either unaided or optically aided viewing. The limiting aperture (D_f) can be 1 mm, 3.5 mm, 7 mm, 11 mm, or somewhere in between. The following examples show techniques for calculating parameters necessary for classifying a laser based on chapter 4 of this bulletin. The hazard class of a laser depends on the effective output power or effective output energy of the laser and the corresponding AEL for each class. The effective output power or effective output energy per pulse is the power or energy transmitted by the proper measurement aperture listed in table E–6. Note that for unaided viewing, the measurement aperture is the same as the limiting aperture. The Class 1 AEL is obtained by multiplying the MPE for the laser by the area of the limiting aperture as specified in table E–5.

b. The Class 2 AEL, for visible wavelength (400 nm–700 nm) lasers only, based on the MPE for 0.25 s viewing, is 1 mW. The Class 3 AEL, based on an acute hazard from the direct beam, is the lesser of $0.03 \cdot C_A$ J in a single pulse or an average power of 0.5 W during a 0.25 s exposure (125 mJ). The Class 3 class has two subsets: Class 3a and Class 3b. The Class 3a AEL is defined as 5 times the Class 1 AEL for invisible wavelength lasers and 5 times the Class 2 AEL (5 mW) for visible wavelength lasers. All other Class 3 lasers are Class 3b. The Class 4 AEL, based on indirect hazards (such as, skin hazard and diffuse reflection hazard) encompasses all lasers that do not meet the AELs for the lesser classes.

c. A classification scheme has been introduced internationally and is likely to replace the current U.S. classification scheme in a few years. Under this classification, all Class 3a lasers will be referred to as Class 3R (for reduced safety requirements), and two new classes will be introduced: Class 1M and Class 2M. These classifications distinguish lasers that are only hazardous for optically aided viewing. Class 1 or Class 2 will be lasers that are not hazardous for either viewing condition, and those that are not an unaided viewing hazard but could be an optically aided viewing hazard are either Class 1M or Class 2M. Class 2M will naturally be restricted to visible (400 nm–700 nm) wavelengths, and neither Class 1M nor 2M lasers can exceed the Class 3b AEL even considering the potential use of optical viewing aids.

EXAMPLE 11. *Q-Switched Doubled Nd:YAG Laser.*

Classify a single-pulse (<1 Hz) Q-switched doubled Nd:YAG laser (532 nm) having an output peak power specified by the manufacturer as 20 mW, a pulse duration of 25 ns, and a laser rod diameter of 5/8 inch.

Solution. The output energy per pulse is—

$$Q = \Phi \cdot t = \left(2 \times 10^{7}\ \text{W}\right) \times \left(2.5 \times 10^{-8}\ \text{s}\right) = 0.5\ \text{J}$$

Where Φ represents the peak power for this laser.

The Class 3b limit for a single pulse is $0.03 \cdot C_A$ J. From table E–3, C_A is equal to 1.0 at the laser wavelength. Therefore, the Class 3b limit is 30 mJ. Since the output energy of this laser (0.5 J) is greater than the Class 3b limit, the laser is a Class 4 laser.

EXAMPLE 12. *Rhodamine 6G Dye Laser.*

Classify a rhodamine 6G dye laser that has a peak output at a wavelength of 590 nm. The energy output is 10 mJ in a 5 mm diameter beam for a duration 1 μs.

Solution. From table E–1, the MPE for a laser with a wavelength between 400 nm - 700 nm, having pulse duration between 1 ns – 18 µs, is 5×10^{-7} J·cm^{-2}. The Class 1 AEL is the product of the MPE and the area of the limiting aperture defined in table E–5. The limiting aperture diameter for a 590 nm laser is 7 mm and the corresponding area is 0.385 cm^2. The Class 1 AEL is—

$$Class 1\ AEL = MPE \times \left(\frac{\pi D_f^2}{4} \right) J \cdot cm^{-2}$$

$$= 5 \times 10^{-7}\ \text{J·cm}^{-2} \times 0.385\ \text{cm}^2 = 1.9 \times 10^{-7}\ \text{J.}$$

The Class 3a AEL is 5 times the Class 1 AEL or 9.6 X 10^{-7} J, and the Class 3b AEL is 0.03·C_A J. C_A at 590 nm is 1, which results in a Class 3b AEL of 30 mJ. Since the laser output of 10 mJ is less than 30 mJ, it is a Class 3b laser.

EXAMPLE 13. *Tunable Laser*.

Classify a tunable laser, which could emit between 0.7 µm–2 µm. The device has been altered to operate only at the 700 nm and 750 nm wavelengths. The radiant energy output in a single pulse is 1.0 mJ at 700 nm and 10 mJ at 750 nm. The laser is single pulsed with a pulse duration of 1.0 µs and a 5-mm beam diameter.

Solution. The MPE for a single 1-µs pulse at these wavelengths is—

$$MPE_{SP} = 5 \times 10^{-7} \cdot C_A\ \text{J} \cdot \text{cm}^{-2}$$

with CA, from table E–3, equaling 1.0 for 700 nm and 1.26 for 750 nm. The output energies at 700 nm and 750 nm are above the Class 1 or 3a AELs (see example 12). The Class 3b AEL (0.03·C_A J/pulse) is 30 mJ at 700 nm and 38 mJ at 750 nm. The laser's 1 mJ and 10 mJ pulses are both below their respective Class 3b AEL making this laser a Class 3b system.

EXAMPLE 14. *1-Watt Argon Laser.*

Classify a 1-watt argon laser, operating at 514.5 nm, used in a communications link.

Solution. This laser could fall into one of several classifications depending on the radiant power that an individual could possibly be exposed to. The laser would be Class 1 if the entire beam path were enclosed, as in a sealed optical pipe. If, as an unenclosed beam, more than 0.5 W is emitted that would be collected by the proper measurement aperture (table E–6), the laser is a Class 4 system. Finally, if after passing through beam-forming optics the effective power in the beam is greater than 5 mW but less than 0.5 W, the laser is Class 3b.

EXAMPLE 15. *632.8 nm Visible Laser.*

Classify a 632.8 nm visible laser (helium neon) used as a remote control switch. The laser is electronically pulsed with a 1-mW peak power output, a pulse duration of 0.1 s (hence an energy of 1×10^{-4} J/pulse), and a beam diameter of 1.0 cm. The recycle time of the laser is 5 s (maximum PRF = 0.2 Hz). Therefore, the laser may not be considered repetitively pulsed.

Solution. Since the pulse duration for the laser is 0.1 s, the exposure duration is also 0.1 s. From table E–1, the MPE is—

$$MPE = 1.8 \cdot t^{0.75} \times 10^{-3}\ \mathrm{J \cdot cm^{-2}} = 3.2 \times 10^{-4}\ \mathrm{J \cdot cm^{-2}}\ \text{or}\ 3.2\ \mathrm{W \cdot cm^{-2}}\ \textit{peak power}\ .$$

The Class 1 AEL is the product of the MPE and the area of the 7-mm limiting aperture ($0.385\ \mathrm{cm}^2$). Therefore, the Class 1 AEL is 1.23 mW for a single pulse making this helium neon laser Class 1. If multiple pulses are considered, rule 2 yields 1.18 mW for 2 pulses occurring in 5.1 s, and for rule 3, $n^{-0.25}$ is 0.84 for 2 pulses, reducing the Class 1 AEL to 1.03 mW and the laser is still Class 1.

B–9. Central beam irradiance or radiant exposure for circular beams

A laser's irradiance or radiant exposure at the cornea is compared to the MPE (figure B–3). Often, the beam irradiance or radiant exposure is not provided in a laser's specifications. However, if the laser is a single mode and has a Gaussian or nearly top-hat beam profile, the central beam values may be obtained from the beam diameter specified at 1/e points and the beam radiant power or energy. The relationships are—

Equation 5 $$H_O = \frac{4Q}{\pi a^2} = \frac{1.27Q}{a^2};$$

Equation 6 $$E_O = \frac{4\Phi}{\pi a^2} = \frac{1.27\Phi}{a^2}$$

For safety evaluations, instead of the center beam values H_O and E_O, values of H and E averaged over the correct limiting aperture (table E–5) are necessary. For retinal hazards, visible and near-infrared lasers, the degree of hazard is dependent on the total energy reaching the retina. For this spectral region a limiting aperture of 7 mm is used, representing the pupil size. Other limiting aperture sizes (D_f) are used for wavelengths outside the retinal hazard region. A logical method for calculating E and H is—

Equation 7 $$E = \frac{4\Phi}{\pi\left[\max\left(a, D_f\right)\right]^2} = \frac{1.27\Phi}{\left[\max\left(a, D_f\right)\right]^2}$$ and

Equation 8 $$H = \frac{4Q}{\pi\left[\max\left(a, D_f\right)\right]^2} = \frac{1.27Q}{\left[\max\left(a, D_f\right)\right]^2}$$

Where max(a, D_f) represents the larger of either the beam diameter (specified at 1/e points) or the limiting aperture size.

EXAMPLE 16. *A Single-Pulse (>1 Hz) Q-Switched Doubled Nd:YAG Laser (532 nm).*

A single-pulse (<1 Hz) Q-switched doubled Nd:YAG laser (532 nm) has an output peak power specified by the manufacturer of 7 W, a pulse duration of 25 ns, and a 5-mm exit beam diameter. Determine whether the laser exceeds the MPE. (Keep in mind that peak power is sometimes misused and may actually indicate maximum average power.)

Solution. The MPE for this laser (table E–1) is 5.0×10^{-7} J·cm^{-2}. The output energy per pulse is 1.75×10^{-7} J (see example 11). The diameter of the laser beam near the exit aperture is 5 mm, but in this region of the spectrum, D_f is 7 mm. The radiant exposure of the laser is—

$$H = \frac{1.27Q}{\left[\max\left(a, D_f\right)\right]^2} = \frac{1.27\left(1.75\times10^{-7}\right)}{\left(0.7\right)^2} = 4.54\times10^{-7}\ \mathrm{J\cdot cm^{-2}}\,.$$

Since 4.54×10^{-7} J·cm^{-2} is less than 5.0×10^{-7} J·cm^{-2}, the laser does not exceed the MPE.

EXAMPLE 17. 1-Argon Laser.

A 1-W argon laser operating at 514.5 nm is to be used in a communications link. Determine under what conditions the emergent beam would not be considered a skin hazard.

Solution. The MPEs for skin exposure can be found in table E–4. For exposures greater than 10 s, the MPE is—

$$MPE_{SKIN} = 0.2 \cdot C_A\ \mathrm{W\cdot cm^{-2}}.$$

C_A for this wavelength is 1.0, so the MPE for skin is 0.2 W·cm^{-2}. The limiting aperture (table E–5) for skin is 3.5 mm. Since the emergent beam power is 1 W, the size of the beam would have to be large enough such that irradiance of the laser was less than the 0.2 W·cm^{-2} MPE.

Therefore,

$$MPE_{SKIN} = E_O = \frac{4\Phi}{\pi a^2} .$$

Solving for *a* yields—

$$a = \sqrt{\frac{4\Phi}{\pi \cdot MPE}} = \sqrt{\frac{4(1\,\mathrm{W})}{\pi\left(0.2\,\frac{\mathrm{W}}{\mathrm{cm}^2}\right)}} = 2.52\,\mathrm{cm} .$$

The beam diameter at the exit aperture for this laser must be greater than 2.5 cm to prevent a possible skin hazard.

B-10. Beam diameter and beam divergence for circular beams

The beam diameter used in safety analysis is the diameter at 1/e of peak irradiance. Therefore, an aperture that is the same size as the beam diameter, placed in the center of the beam, would collect 63 percent of the energy or power rather than the 87.5 percent or 100 percent that one would expect. Often the beam diameter or divergence is specified at $1/e^2$ points rather than 1/e points so that equations 5 and 6 would calculate average values rather than the central beam values. In this case, the values of diameter or divergence are divided by the $\sqrt{2}$ to obtain the 1/e values. Calculate the emergent beam diameter (*a*) from a measured fraction of total radiant energy passing through an aperture for a Gaussian beam using the following equation:

Equation 9 $$a = \sqrt{\frac{-d^2}{\ln[1 - f(d)]}}$$

Where *d* is the diameter of the aperture and *f(d)* represents the fraction of the beam energy passing through the aperture. At a distance from the laser, the beam is no longer Gaussian but may be approximated by a Gaussian shape; therefore, the following relation may be used—

Equation 10 $$D_L = \sqrt{\frac{-d^2}{\ln[1 - f(d)]}} .$$

For a Gaussian shape, the fraction of the total power or energy transmitted by a measurement aperture (D_m), may be determined from the following equations:

Equation 11 $$\frac{F_d}{f_0} = 1 - e^{-\left(\frac{D_m}{D_L}\right)^2}$$, or

Equation 12 $$\frac{Q_d}{Q_0} = 1 - e^{-\left(\frac{D_m}{D_L}\right)^2}.$$

One way to calculate beam divergence is to compare the beam diameter at a distance to the initial beam diameter.

EXAMPLE 17. *Calculation of Maximum and Central Beam Irradiance.*

From a Gaussian shaped beam, calculate the maximum central beam irradiance and the central beam irradiance averaged over a 7-mm aperture from a laser with a 5-mW output and an 8-mm beam diameter.

Solution.

a. Maximum beam irradiance. From equation 6—

$$E_O = \frac{1.27\left(5 \times 10^{-3}\ \mathrm{W}\right)}{\left(0.8\,\mathrm{cm}\right)^2}$$

$$= 9.9 \times 10^{-3}\ \mathrm{W \cdot cm^{-2}}.$$

b. Maximum beam irradiance averaged over 7 mm. The fraction of the laser power that would be transmitted by the 7-mm aperture from equation 11 is—

$$\frac{F_d}{f_0} = 1 - e^{-\left(\frac{0.7}{0.8}\right)^2} = 0.535$$

The area of a 7-mm aperture is 0.385 cm^2. The beam irradiance averaged over a 0.7-cm diameter aperture is—

$$E = \frac{5\,\mathrm{mW} \times 0.535}{0.385\,\mathrm{cm}^2} = 6.95\ \mathrm{mW \cdot cm^{-2}}.$$

EXAMPLE 18. *Laser Beam Diameter.*

Find the beam diameter to be used in calculations in hazard analysis. A laser beam diameter is specified as being 3 mm in diameter as measured at $1/e^2$ of peak-irradiance points. The beam is further specified to be single mode and Gaussian.

Solution. Since the beam is Gaussian, we may use the relation that the beam diameter measured at $1/e^2$ points is greater by a factor of $\sqrt{\mathbf{2}}$ = 1.41. The beam diameter for hazard analysis is measured at 1/e. Therefore,

$$a = \frac{0.3\,\text{cm}}{\sqrt{2}} = 0.21\,\text{cm}$$

EXAMPLE 19. *Gaussian Laser Beam.*

From a Gaussian shaped beam, find the approximate beam diameter of a Gaussian laser beam having a total output power of 5 mW and a measured power of 1 mW passing through a 7-mm aperture.

Solution. Using Equation 9, *f(d)* equals 0.2 (1mW/5mW)—

$$a = \sqrt{\frac{-(0.7)^2}{\ln(1-0.2)}} = 1.5\,\text{cm}$$

EXAMPLE 20. *Maximum Percentage of Total Power.*

Find the maximum percentage of total power of a 3-mW helium-neon laser that will pass through a 7-mm aperture if the beam diameter specified at $1/e^2$ points is 1.6 cm.

Solution. The beam diameter used for safety calculations (1/e points) is 1.1 cm (see example 18). The power that passes through an aperture of diameter D_f (equation 11) is given by—

$$F_d = f_0\left[1 - e^{-\left(\frac{D_f}{D_L}\right)^2}\right] =$$

$$= 3\left[1 - \mathrm{e}^{-\left(\frac{0.7\,\text{cm}}{1.1\,\text{cm}}\right)^2}\right] = 1\ \text{mW}$$

B-11. Beam irradiance or radiant exposure for rectangular and elliptical beams
The radiant exposure for either a rectangular or elliptical beam can be calculated by making modifications to equations 7 and 8. For a rectangular beam—

Equation 14 $$E = \frac{F}{\left[\max\left(b_1, D_f\right)\right]\cdot\left[\max\left(c_1, D_f\right)\right]}, \text{ and}$$

Equation 15 $$H = \frac{Q}{\left[\max\left(b_1, D_f\right)\right]\cdot\left[\max\left(c_1, D_f\right)\right]}.$$

For an elliptical beam—

Equation 16 $$E = \frac{1.27\,\Phi}{\left[\max\left(b, D_f\right)\right]\cdot\left[\max\left(c, D_f\right)\right]}, \text{ and}$$

Equation 17 $$H = \frac{1.27Q}{\left[\max\left(b, D_f\right)\right]\cdot\left[\max\left(c, D_f\right)\right]}$$

EXAMPLE 21. *Beam Irradiance.*

Find the beam irradiance at 10 cm from an 860 nm diode-laser illuminator. The beam shape of the illuminator is rectangular with the following parameters: $\Phi = 2.5\text{W}$, $b_1 = 2.5$ cm, and $c_1 = 4$ cm.

Solution. Using equation 14—

$$E = \frac{\Phi}{\left[\max\left(b_1, D_f\right)\right]\cdot\left[\max\left(c_1, D_f\right)\right]} =$$

$$= \frac{2.5\,\text{W}}{(2.5\,\text{cm})\cdot(4\,\text{cm})} = 0.25\,\text{W}\cdot\text{cm}^{-2}$$

EXAMPLE 22. *Radiant Exposure.*

Find the radiant exposure of a 1064-nm laser designator emitting energy of 11 μJ/pulse with an elliptical beam shape, having dimensions of 2.5 mm × 12 cm.

Solution. The radiant exposure used for safety evaluation is—

$$H = \frac{1.27Q}{\left[\max\left(b, D_f\right)\right]\cdot\left[\max\left(c, D_f\right)\right]}$$
$$= \frac{1.27\times 11\,\mu\text{J}}{\left(0.7\,\text{cm}\right)\cdot\left(12\,\text{cm}\right)} = 1.66\ \mu\text{J}\cdot\text{cm}^{-2}\,.$$

B-12. Beam diameter versus range

The beam diameter of a Gaussian-shaped beam changes with range from the laser exit port. When the beam waist occurs deep within the cavity of the laser, the best approximation of the beam diameter with range is—

Equation 18 $$D_L = a + r\phi$$

EXAMPLE 23. *Diameter of a Gaussian Laser Beam.*

Find the diameter of a Gaussian laser beam at 1 km where the emergent beam waist occurs within the laser cavity, the diameter is 10 cm and the beam divergence is 0.1 mrad.

Solution.

$$D_L = 10\,\text{cm} + \left(10^5\,\text{cm}\right)\cdot\left(10^{-4}\,\text{radians}\right) = 20\,\text{cm}$$

If the beam waist for the laser occurs at or very near the exit port, the beam diameter change with distance becomes more of a hyperbolic function than the linear one for the internal beam waist. See figure B–6. The equation now becomes—

Equation 19 $$D_L = \sqrt{a^2 + r^2\phi^2}$$

EXAMPLE 24. *Beam Waist at Exit Port.*

Solve Example 23 assuming a beam waist occurring very near the exit port.

Solution.

$$D_L = \sqrt{\left(10\,\text{cm}\right)^2 + \left(10^5\,\text{cm}\right)^2\cdot\left(10^{-4}\,\text{radians}\right)^2} = 14\,\text{cm}$$

There are instances where the beam waist occurs a distance in front of the laser's exit port (figure B–6). In this case, the beam diameter gets smaller from the exit port until the beam waist is reached and then begins to expand. For a Gaussian beam of this nature, the beam expansion equation becomes—

Equation 20 $$D_L = \sqrt{D_w^2 + (r - r_0)^2 \cdot \phi^2}$$

D_w is the beam diameter at the waist, r_0 is the distance from the exit port to the beam waist, and r is the distance from the exit port to the point where the beam diameter is D_L.

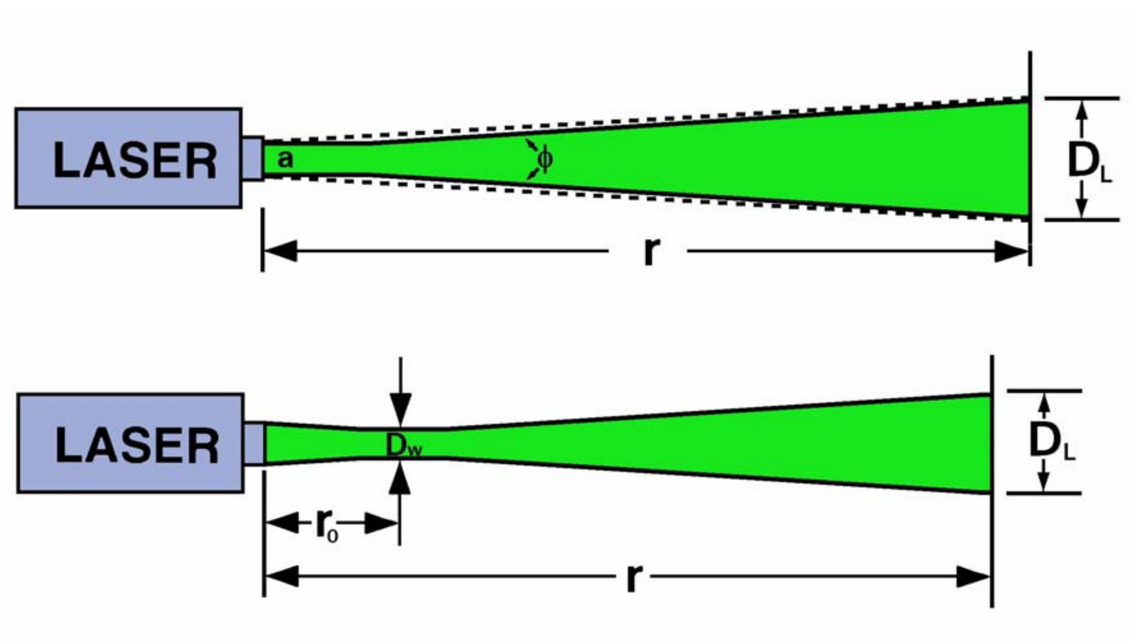

Figure B–6. Beam expansion with distance from the laser

B-13. Atmospheric attenuation
Beam irradiance (E) or radiant exposure (H) for a nondiverging beam at range, *r*, which is attenuated by the atmosphere is—

Equation 21 $$E = E_0 \cdot e^{-\mu r}$$

Equation 22 $$H = H_0 \cdot e^{-\mu r}$$

The attenuation coefficient μ varies from 10^{-4} per cm in thick fog to 10^{-7} in air of very good visibility. The Rayleigh scattering coefficient at 694.3 nm is 4.8×10^{-8} cm^{-1}, and 1.8×10^{-7} cm^{-1} at 500 nm. The effect of aerosols in even the cleanest atmospheres usually raises μ at 694.3 nm to at least 5×10^{-7} cm^{-1}.

B-14. Laser range equation
The average irradiance for a circular beam at range, *r*, is the total power in the beam at that range divided by the area of the beam at that range; likewise, the radiant exposure in a non-turbulent medium is the total energy in the beam at that range divided by the total area. The laser range

equation, a formula for computing the irradiance or radiant exposure for a laser at any distance, is formed from the combinations of the equation for irradiance (equation 6) or radiant exposure (equation 5) with the appropriate equation for atmospheric attenuation (equations 21 and 22) and beam expansion (equation 19). The resultant range equations for circular beams are—

Equation 23 $$E = \frac{\Phi e^{-\mu r}}{\pi\left[\frac{\sqrt{a^2 + r^2\phi^2}}{2}\right]^2} = \frac{1.27\Phi e^{-\mu r}}{a^2 + r^2\phi^2}$$ and

Equation 24 $$H = \frac{Qe^{-\mu r}}{\pi\left[\frac{\sqrt{a^2 + r^2\phi^2}}{2}\right]^2} = \frac{1.27Qe^{-\mu r}}{a^2 + r^2\phi^2}$$

EXAMPLE 25. *Radiant Exposure.*

Find the radiant exposure at 1 km (10^5 cm) of a 0.25 J Q-switched Nd:YAG laser rangefinder. The laser has a beam divergence of 0.1 mrad (10^{-4} radian) and an emergent beam diameter of 0.7 cm. Assume an atmospheric attenuation factor of 1×10^{-7} cm^{-1}.

Solution. Since the laser output parameters are given in terms of energy, equation 24 is the appropriate formula to use.

$$H = \frac{(1.27)(0.25\,\text{J})\text{e}^{-(10^{-7}\,\text{cm}^{-1})(10^5\,\text{cm})}}{\left[(0.7\,\text{cm})^2 + (10^5\,\text{cm}\times 10^{-4}\,\text{rad})^2\right]}$$

$$H = \frac{(1.27)(0.25\,\text{J})(0.99)}{\left[(0.7)^2 + (10)^2\right]\text{cm}^2}$$

$$H = 3.13\times 10^{-3}\,\text{J}\cdot\text{cm}^{-2}.$$

For lasers that form a waist downrange from the laser exit port, equations 23 and 24 are transformed by applying equation 20 for beam expansion component instead of equation 19 used for non-focused beams. The location of the waist (r_0) and the diameter of the beam at the waist (D_w) are important measurements, although only a rough approximation of each is necessary for laser safety calculations. The laser range equations become—

Equation 25 $$E = \frac{1.27\Phi e^{-\mu r}}{D_w^2 + (r - r_0)^2 \cdot \phi^2}$$ and

Equation 26 $$H = \frac{1.27Qe^{-\mu r}}{D_w^2 + (r - r_0)^2 \cdot \phi^2}.$$

EXAMPLE 26. *Irradiance.*

Find the irradiance at 70 m from a low power CW tactical laser pointer (λ = 830 nm) with an output power of 1.5 mW, a beam diameter of 1.0 cm at the exit port, a beam waist located 5 m in front of the laser and measured to be 0.7 cm in diameter, and a beam divergence of 0.3 mrad. Assume an atmospheric attenuation factor of 1×10^{-7} cm^{-1}.

Solution. The irradiance at 70 m is—

$$E = \frac{(1.27)(5 \times 10^{-3}\,\mathrm{W})(1)}{\left[(.7)^2 + (7000 - 500)^2 (0.3 \times 10^{-3})^2\right] \mathrm{cm}^2}$$

$$E = 1.48 \times 10^{-3}\ \mathrm{W \cdot cm^{-2}}.$$

The MPE for this laser is 1.82×10^{-3} W·cm^{-2}. Therefore, an individual exposed to this laser at 70 m would not be in danger. Elliptical or rectangular beam radiant exposures can be calculated much like that of a circular beam. The equations for beam expansion for these type beams must be substituted into the equation for circular beams. The values for *b* and *c* are not measured close to the beam waist if the waist occurs at some point behind the laser exit port. The radiant exposure (*H*) and irradiance (*E*) equations for an elliptical beam are—

Equation 27 $$E = \frac{1.27\Phi e^{-\mu r}}{[b + r\phi_1] \cdot [c + r\phi_2]}$$ and

Equation 28 $$H = \frac{1.27Qe^{-\mu r}}{[b + r\phi_1] \cdot [c + r\phi_2]}.$$

For rectangular beams, the equations become—

Equation 29 $$E = \frac{1.27\Phi e^{-\mu r}}{[b_1 + r\phi_1] \cdot [c_1 + r\phi_2]}$$ and

Equation 30 $$H = \frac{1.27Qe^{-\mu r}}{[b_1 + r\phi_1]\cdot[c_1 + r\phi_2]}.$$

The expansion equation of a laser beam, in any two orthogonal axes, is different for many of these types of lasers. In many cases, the laser beam may come to a focus in front of the laser in one axis, while it is constantly diverging in the other.

EXAMPLE 27. *Gallium Arsenide Laser Illuminator*.

A gallium arsenide laser illuminator is used for training. Find the beam irradiance at 50 m for a laser with a rectangular beam and the following parameters:

b_1 = 1.4 cm, c_1 = 2.1 cm, ϕ_1 = 55 mrad, ϕ_2 = 21 mrad, Φ = 2.4 W

Solution.

$$E = \frac{\Phi e^{-\mu r}}{[b_1 + r\phi_1]\cdot[c_1 + r\phi_2]}$$

$$E = \frac{(2.4\,\mathrm{W})\cdot \mathrm{e}^{-(10^{-7}\,\mathrm{cm}^{-1})(5000\,\mathrm{cm})}}{[1.4 + 5000\cdot(55\times10^{-3})]\mathrm{cm}\times[2.1 + 5000\cdot(21\times10^{-3})]\mathrm{cm}}$$

$$E = \frac{2.4\,\mathrm{W}}{2.96\times10^{4}\,\mathrm{cm}^2} = 8.1\times10^{-5}\,\mathrm{W}\cdot\mathrm{cm}^{-2}$$

EXAMPLE 28. *One Dimension Beam Focus.*

Solve the previous example assuming that the beam is focused in one dimension. Use the same parameters with the following changes: ϕ_2 = -1.2 mrad (focused beam), no external waist in *b* dimension, D_w (c dimension) = 0.7 cm, r_0 (c dimension) = 5 m.

Solution. Equation 29 needs to be modified since the beam is focused in one dimension but not the other. Note—

$$D_{L1} = b_1 + r\phi_1$$

$$D_{L1} = 1.4 + (5000\times55\times10^{-3}) = 276 \text{ cm}$$

$$D_{L2} = \sqrt{D_w^2 + (r - r_0)^2\cdot\phi_2^2}$$

$$D_{L2} = \sqrt{(0.7)^2 + (5000\,\text{cm} - 500\,\text{cm})^2(-1.2\times10^{-3})^2}$$

$$D_{L2} = 5.45\,\text{cm}$$

$$E = \frac{\Phi e^{-\mu r}}{(D_{L1})(D_{L2})}$$

$$E = \frac{2.4\,\text{W}}{(276\,\text{cm})(5.45\,\text{cm})} = 1.6\times10^{-3}\,\text{W}\cdot\text{cm}^{-2}$$

B–15. Nominal ocular hazard distance
For unaided viewing conditions, solving equations 23 and 24 for *r*, and replacing H or E with the correct MPE, will yield a value of r equal to r_{NOHD} (see figure B–7). This is a worst-case estimate for the NOHD since the atmospheric attenuation coefficient was ignored.

Equation 31 $$r_{NOHD} = \frac{1}{\phi}\sqrt{\frac{1.27\Phi}{MPE} - a^2} \quad \text{(for CW lasers)}$$

Equation 32 $$r_{NOHD} = \frac{1}{\phi}\sqrt{\frac{1.27Q}{MPE} - a^2} \quad \text{(for pulsed lasers)}$$

EXAMPLE 29. r_{NOHD}

Find the r_{NOHD} (ignoring atmospheric effects) for a 0.25-J, Q-switched, ruby laser rangefinder that has a beam divergence of 1 mrad (10^{-3} radian), a pulse width of 25 ns and an emergent beam diameter of 0.7 cm.

Solution. The MPE from table E–1 is 0.5 $\mu J\cdot cm^{-2}$.

$$r_{NOHD} = \frac{1}{1\times10^{-3}}\sqrt{\frac{1.27(0.25)}{5\times10^{-7}} - (0.7)^2}$$

$$r_{NOHD} = 7.97\,\text{km}\,.$$

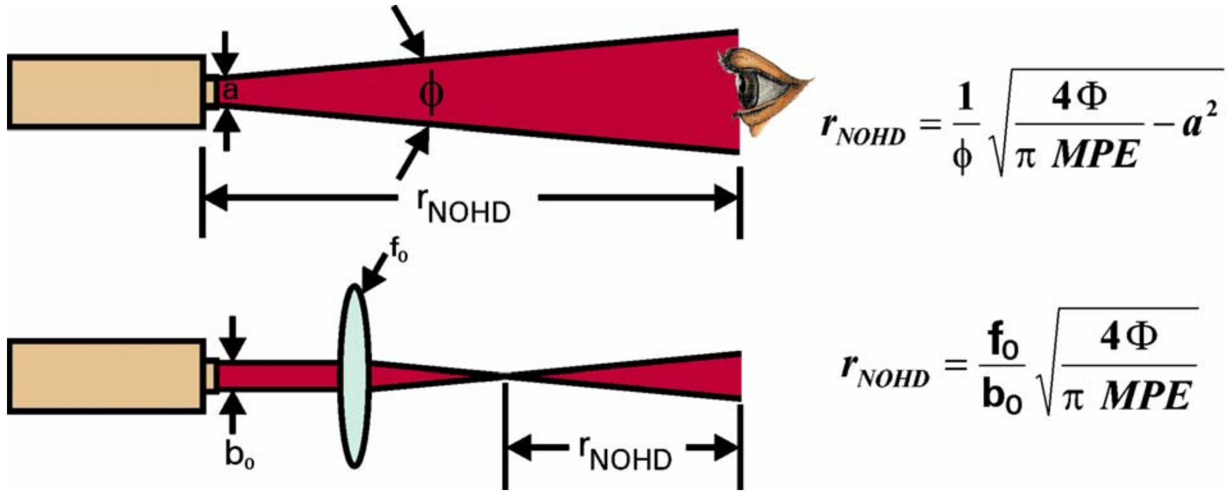

Figure B–7. Using the laser range equation to determine nominal ocular hazard distances

B-16. Viewing aided by an optical system

The hazard of viewing a laser intrabeam is increased when optical viewing aids such as binoculars are used. The hazard may increase by as much as the square of the magnifying power of the optic. Standard 7×50 binoculars are used as the basis for laser hazard classification. Because these types of magnifying devices cannot focus at distances closer than 2 m, measurements for laser hazard classification are taken at this distance (2 m). The optical gain, G, is defined as the ratio of the irradiance or radiant exposure at the cornea when viewing is aided by an optical system, to that which is received by the unaided eye. The equation for optical gain is—

Equation 33 $$G = \frac{D_0^2}{D_e^2} = P^2 .$$

D_0 is the diameter of the entrance aperture of the optical system and D_e is the exit aperture diameter. This equation is also assuming 100 percent transmission of the laser light through the optics. P is the power of the optics system.

EXAMPLE 30. *Standard 7×50 Binocular*.

For a pair of standard 7×50 binoculars the optical power is 7, the entrance aperture is 5.0 cm, and the exit aperture diameter is slightly larger than 7 mm (the limiting aperture size for lasers in the retinal hazard region, 400 nm–1400 nm). Find the precise exit aperture diameter.

Solution. Using equation 33 and solving for D_e yields—

$$D_e = \sqrt{\frac{D_0^2}{P^2}}$$

$$D_e = \sqrt{\frac{5^2}{7^2}} = 0.714 \text{ cm}$$

The equation for optical gain is not completely realistic, in that it doesn't consider transmission losses through the optical system. All optics transmits less than 100 percent of power or energy falling on them. The maximum transmission (τ_λ) through optics, for the visible (400 nm–700 nm) portion of the spectrum, is assumed to be 90 percent and at all other wavelengths (302 nm–2800 nm) τ_λ is assumed to be no more than 70 percent. The collecting aperture (D_c) is often the same size as the measurement aperture (D_m) listed in table E–6 (5 cm for retinal hazard region). The collecting aperture (D_c) is, therefore, the minimum of the optical power (P) multiplied by the limiting aperture (D_f) and the entrance diameter of the optics (D_0).

$$D_c = \min\left(P \times D_f , D_0\right)$$

For beam diameters less than D_c, the full effect of the optics will not be realized since the beam diameter at the exit port will be reduced to less than the limiting aperture. Therefore, the effective gain equation is—

Equation 34 $$G_{eff} = \tau_\lambda \times \frac{\min\left(D_c^2 , D_L^2\right)}{D_f^2}$$

In order to calculate the NOHD for a laser system when optics may be used to view the laser, either purposefully or not, the effective gain of the system must be incorporated into equations 31 and 32. Note that for low-power systems, G_{eff} at the location of the NOHD may still depend on D_L, and will, therefore, make the equations difficult to solve. The equations for NOHD when optical aids are used (NOHD–M) are—

Equation 35 $$r_{NOHD(M)} = \frac{1}{\phi}\sqrt{\frac{1.27\Phi \cdot G_{eff}}{MPE} - a^2} \quad \text{(for CW lasers)}$$

Equation 36 $$r_{NOHD(M)} = \frac{1}{\phi}\sqrt{\frac{1.27Q \cdot G_{eff}}{MPE} - a^2} \quad \text{(for pulsed lasers)}$$

See Table B-2 for atmospherically corrected NOHD values.

Table B–2.
Atmospherically corrected values of nominal ocular hazard distance (NOHD) in kilometers, assuming $\mu = 0.05$ km^{-1}, when the NOHD, with or without optics in vacuum (NOHD(v)), is known

NOHD(v) (km)	NOHD (km)	NOHD(v) (km)	NOHD (km)	NOHD(v) (km)	NOHD (km)	NOHD(v) (km)	NOHD (km)	NOHD(v) (km)	NOHD (km)	NOHD(v) (km)	NOHD (km)
0.10	0.10	4.80	4.31	9.50	7.81	52.00	26.70	99.00	38.10	560.00	78.60
0.20	0.20	4.90	4.39	9.60	7.88	53.00	27.00	100.00	38.30	570.00	79.00
0.30	0.30	5.00	4.47	9.70	7.95	54.00	27.30	110.00	40.20	580.00	79.50
0.40	0.40	5.10	4.55	9.80	8.02	55.00	27.60	120.00	42.00	590.00	79.90
0.50	0.49	5.20	4.63	9.90	8.09	56.00	27.90	130.00	43.70	600.00	80.40
0.60	0.59	5.30	4.71	10.00	8.20	57.00	28.20	140.00	45.20	610.00	80.80
0.70	0.69	5.40	4.79	11.00	8.80	58.00	28.50	150.00	46.70	620.00	81.30
0.80	0.78	5.50	4.87	12.00	9.50	59.00	28.80	160.00	48.10	630.00	81.70
0.90	0.88	5.60	4.95	13.00	10.10	60.00	29.00	170.00	49.40	640.00	82.10
1.00	0.98	5.70	5.03	14.00	10.70	61.00	29.30	180.00	50.70	650.00	82.50
1.10	1.07	5.80	5.11	15.00	11.30	62.00	29.60	190.00	51.90	660.00	83.00
1.20	1.17	5.90	5.18	16.00	11.90	63.00	29.90	200.00	53.10	670.00	83.40
1.30	1.26	6.00	5.26	17.00	12.50	64.00	30.10	210.00	54.20	680.00	83.80
1.40	1.35	6.10	5.34	18.00	13.00	65.00	30.40	220.00	55.30	690.00	84.20
1.50	1.45	6.20	5.41	19.00	13.50	66.00	30.70	230.00	56.30	700.00	84.60
1.60	1.54	6.30	5.49	20.00	14.10	67.00	30.90	240.00	57.30	710.00	84.90
1.70	1.63	6.40	5.57	21.00	14.60	68.00	31.20	250.00	58.30	720.00	85.30
1.80	1.72	6.50	5.64	22.00	15.10	69.00	31.40	260.00	59.20	730.00	85.70
1.90	1.82	6.60	5.72	23.00	15.60	70.00	31.70	270.00	60.10	740.00	86.10
2.00	1.91	6.70	5.80	24.00	16.10	71.00	31.90	280.00	61.00	750.00	86.40
2.10	2.00	6.80	5.87	25.00	16.50	72.00	32.20	290.00	61.80	760.00	86.80
2.20	2.09	6.90	5.95	26.00	17.00	73.00	32.40	300.00	62.60	770.00	87.10
2.30	2.18	7.00	6.02	27.00	17.50	74.00	32.70	310.00	63.50	780.00	87.50
2.40	2.27	7.10	6.10	28.00	17.90	75.00	32.90	320.00	64.20	790.00	87.90
2.50	2.36	7.20	6.17	29.00	18.30	76.00	33.20	330.00	65.00	800.00	88.20
2.60	2.45	7.30	6.24	30.00	18.80	77.00	33.40	340.00	65.70	810.00	88.50
2.70	2.53	7.40	6.32	31.00	19.20	78.00	33.60	350.00	66.50	820.00	88.90
2.80	2.62	7.50	6.39	32.00	19.60	79.00	33.90	360.00	67.20	830.00	89.20
2.90	2.71	7.60	6.47	33.00	20.00	80.00	34.10	370.00	67.80	840.00	89.50
3.00	2.80	7.70	6.54	34.00	20.40	81.00	34.30	380.00	68.50	850.00	89.90
3.10	2.88	7.80	6.61	35.00	20.80	82.00	34.60	390.00	69.20	860.00	90.20
3.20	2.97	7.90	6.68	36.00	21.20	83.00	34.80	400.00	69.80	870.00	90.50
3.30	3.06	8.00	6.76	37.00	21.60	84.00	35.00	410.00	70.50	880.00	90.80
3.40	3.14	8.10	6.83	38.00	22.00	85.00	35.20	420.00	71.10	890.00	91.10
3.50	3.23	8.20	6.90	39.00	22.30	86.00	35.40	430.00	71.70	900.00	91.50
3.60	3.31	8.30	6.97	40.00	22.70	87.00	35.70	440.00	72.30	910.00	91.80
3.70	3.40	8.40	7.04	41.00	23.00	88.00	35.90	450.00	72.80	920.00	92.10
3.80	3.48	8.50	7.11	42.00	23.40	89.00	36.10	460.00	73.40	930.00	92.40
3.90	3.57	8.60	7.19	43.00	23.70	90.00	36.30	470.00	74.00	940.00	92.70
4.00	3.65	8.70	7.26	44.00	24.10	91.00	36.50	480.00	74.50	950.00	93.00
4.10	3.73	8.80	7.33	45.00	24.40	92.00	36.70	490.00	75.00	960.00	93.30
4.20	3.82	8.90	7.40	46.00	24.80	93.00	36.90	500.00	75.60	970.00	93.60
4.30	3.90	9.00	7.47	47.00	25.10	94.00	37.10	510.00	76.10	980.00	93.80
4.40	3.98	9.10	7.54	48.00	25.40	95.00	37.30	520.00	76.60	990.00	94.10
4.50	4.07	9.20	7.61	49.00	25.70	96.00	37.50	530.00	77.10	1000.00	94.40
4.60	4.15	9.30	7.68	50.00	26.10	97.00	37.70	540.00	77.60	2000.00	114.40
4.70	4.23	9.40	7.75	51.00	26.40	98.00	37.90	550.00	78.10	3000.00	126.60

EXAMPLE 31. *Calculate the NODH-M for Example 29.*

Calculate the NOHD–M for example 29 (Q–switched, ruby rangefinder, 0.25 J per pulse, 1 mrad divergence, exit beam diameter of 7 mm) when the laser is viewed through 7×50 binoculars. Use table B–1 to correct the calculated result for atmospheric attenuation of 5 × 10^{-7} cm^{-1} (0.05 km^{-1}).

Solution. The effective gain must be calculated for transmission of ruby laser light through 7×50 binoculars and then entered into equation 36. The MPE for a single pulsed (25 ns) ruby laser is 5× 10^{-7} J·cm^{-2}.

$$G_{eff} = 0.9 \times \left(\frac{\min\left[(5\,\text{cm})^2, (4.9\,\text{cm})^2\right]}{(0.7\,\text{cm})^2} \right) = 44$$

$$r_{NOHD(M)} = \frac{1}{1\times10^{-3}} \sqrt{\frac{1.27(0.25\,\text{J})\cdot 44}{5\times10^{-7}\,\text{J}\cdot\text{cm}^{-2}} - (0.7\,\text{cm})^2}$$

$$r_{NOHD(M)} = 52.9\ \text{km}$$

When atmospheric attenuation is taken into account, $r_{NOHD(M)}$ = 27 km.

B-17. Hazards from specular reflections

Specular reflections (see chapters 4 and 6) are caused by flat mirror-like surfaces. When a laser beam strikes a specular surface, the beam could remain collimated sending the laser power off in a different direction (see figures B–4a and B–4b). Laser targets containing flat glass surfaces (that is, windshields, view blocks) can direct laser energy back at the operator or into an uncontrolled area. The angle the beam makes with the reflecting surface determines where it is reflected and the percentage of the energy that is reflected. At normal incidence (beam perpendicular to surface), a flat glass surface will reflect about 8 percent (4 percent per surface) of the incident energy. At large, near grazing angles, most of the laser energy can be reflected. A flat mirror can reflect nearly 100 percent of the laser energy.

EXAMPLE 32. *Radiant Exposure*.

A 0.05 J, Q-switched, Nd:YAG, laser rangefinder is used in a training scenario conducted in a restricted laser range. The operator's target, located directly in front of the laser, is a high mobility multipurpose wheeled vehicle or high-mobility multipurpose wheeled vehicle (HMMWV) located 2000 m downrange. The HMMWV has a flat glass windshield that could be a potential hazard. The laser operates under the following parameters: a = 0.7 cm, ϕ = 2 mrad, PRF = 10 Hz, and pulse width = 25 ns. What is the potential radiant exposure from a specular reflection from the windshield at the operator's location? Assume that the atmospheric attenuation factor is 5×10^{-7} cm^{-1}. Would the laser operator be exposed to laser radiation in excess of the MPE?

Solution. Calculate the MPE from table E–1 and compare that to the laser operator's potential exposure. Since the windshield is a piece of glass at nearly normal incidence to the laser, the reflectivity would be about 8 percent (4 percent from front surface of windshield and 4 percent from back surface). The overall distance that the beam would travel from the laser to the target and back to the laser is 4000 m. The operator's exposure is simply 8 percent of the radiant exposure at 4000 m. Note that for much more collimated laser systems, surface imperfections and slight curvature of the windshield will significantly increase the beam divergence of the reflected beam.

The MPE for rule 3 is the most restrictive of the three rules. For a 10-s exposure duration, the operator could be exposed to 100 pulses. The MPE is—

$$MPE = MPE_{SP} \times C_P$$

$$MPE / pulse = \left(5\times 10^{-6}\,\mathrm{J}\cdot\mathrm{cm}^{-2}\right)\cdot 0.316 = 1.58\times 10^{-6}\,\mathrm{J}\cdot\mathrm{cm}^{-2}$$

From equation 24, the radiant exposure at 4000 m is—

$$H = \frac{1.27\cdot\rho_\lambda\cdot Qe^{-\mu r}}{a^2 + r^2\phi^2}$$, where ρ_λ is the spectral reflectance at λ.

Therefore,

$$H = \frac{(1.27)(0.08)(5\times 10^{-2}\,\mathrm{J})(0.819)}{(0.7\mathrm{cm})^2 + \left[(4\times 10^5\,\mathrm{cm})(2\times 10^{-3}\,\mathrm{rad})\right]^2}$$

$$H = 6.5\times 10^{-9}\,\mathrm{J}\cdot\mathrm{cm}^{-2}$$

In this example, the operator's exposure would be well below the MPE, making it safe to conduct the test. The windshield was assumed to be flat, but surface curvature could decrease or increase the radiant exposure at the operator's position. The effect of the atmosphere in this case was not significant. In situations where the exposure is approaching the MPE, it is a good safety practice to wear laser eye protectors, use a non-reflective target, or orient the target such that the reflected energy would be directed into the ground or an unoccupied area.

B-18. Hazards from diffuse reflections

Powerful lasers are capable of producing diffuse reflections (figure B–5) from matte surfaces in excess of the MPE for that laser. The hazard from a diffuse reflection is related to the radiant exposure or irradiance at the viewer's location. These types of reflections are hazardous when the reflector is close to the laser exit port and the observer's eye is near the diffusely reflecting surface. The hazard is reduced very quickly as the laser beam striking the target gets larger and/or the observer gets farther from the reflective surface. The reflected radiant exposure or irradiance for a diffuse reflection ($r_1 \gg D_L$) is given by Lambert's law—

$$\text{Equation 37} \qquad E = \frac{\rho_\lambda \Phi \cdot \cos\theta_\upsilon}{\pi r_1^2}$$

$$\text{Equation 38} \qquad H = \frac{\rho_\lambda Q \cdot \cos\theta_\upsilon}{\pi r_1^2}$$

Where Φ represents the laser power, ρ_λ represents the reflectivity of the surface, $\cos\theta_v$ represents the cosine of the angle that the observer is from the normal to the reflecting surface, and r_1 represents the distance from the surface to the observer's eye.

EXAMPLE 33. Find the maximum reflected radiant exposure from a diffuse target of reflectance 0.6 located a distance of 10 meters from the operator of a 0.1-J laser.

Solution. For a maximum return θ_v is 0, resulting in a $\cos\theta_v$ of 1.0. Therefore,

$$H = \frac{(0.6)(0.1\,\text{J})(1.0)}{(3.14)(1\times10^3\,\text{cm})^2}$$

$$H = 1.9\times10^{-8}\,\text{J}\cdot\text{cm}^{-2}$$

EXAMPLE 34. *Diffuse Reflection* r_{NOHD}*.*

Find the hazardous viewing distance (assume at least a 10-s exposure) for looking at a diffuse target having a reflectivity of 0.9 illuminated by a laboratory argon laser (514.5 nm) with Φ = 2 W and a = 2 mm.

Solution. Solve using Equation 37 for a worst-case situation; that is $\cos\theta_v$ is 1.0. Solving for r_1 yields the minimum distance that one could view the diffuse reflection without exceeding the MPE.

The MPE is 1×10^{-3} W·cm^{-2}—

$$r_1 = \sqrt{\frac{\rho_\lambda \cdot \Phi}{E \cdot \pi}}$$

$$r_1 = \sqrt{\frac{(0.9)(2\,\mathrm{W})}{(1 \times 10^{-3}\,\mathrm{W \cdot cm^{-2}})(3.14)}}$$

$$r_1 = 24\ \mathrm{cm}$$

Table B–3 lists the diffuse reflection from pulsed lasers in a retinal hazard region. The listed values are the maximum laser energy striking a target, which would not create a viewing hazard at the distances indicated with various beam diameters.

Table B–3
Diffuse reflection hazard from pulsed lasers in retinal hazard region
(400 nanometers to 1400 nanometers)

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

Notes:
The laser energies listed are based on a calculation that will barely produce a diffuse reflection hazard for Q-switched lasers at various viewing distances. The energies provided are based on various beam diameters, measured at the point of impact on a dull white target.
Notes:
[1] For wavelengths 700 nm–1400 nm, the energy values should be multiplied by the appropriate C_A and C_C correction factor.
[2] For wavelengths 1050 nm–1400 nm, the energy values are also multiplied by a factor of 2.
[3] For repetitive pulse lasers, the repetitive pulse correction factor, C_P should be applied.

Table B–4 lists the diffuse reflection hazards from visible (400 nm–700 nm) CW lasers. The listed values are the maximum laser power striking a target, which would not create a viewing hazard at the distances indicated with various beam diameters.

Table B–4
Diffuse reflection hazards from visible (400 nanometers to 700 nanometers) continuous wave lasers

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

Note: The laser powers listed are based on a calculation that will produce a momentary (0.25 s) diffuse reflection hazard from a CW visible laser. The powers provided for various viewing distances and beam diameters are measured from the point of impact on a dull white target.

B–19. Scanning lasers

For a single exposure to a scanning laser beam, the corneal radiant exposure is given by equations 39 and 40. Repetitive-pulse exposures depend upon distance, r (cm), scan rate, S ($cm \cdot s^{-1}$), and frame rate, Hz.

Equation 39 $$H = \frac{1.27\Phi e^{-\mu r}}{D_L\left(rS\theta_s\right)}$$ for $D_L > d_e$, and

Equation 40 $$H = \frac{1.27\Phi e^{-\mu r}}{d_e\left(rS\theta_s\right)}$$ for $D_L < d_e$.

The applicable MPEs depend upon the repetitive nature of the exposure and the width of a single pulse, *t*. The maximum value of *t* is *1/S* and the PRF is *S* if each scan passes over the eye.

Equation 41 $$t = \frac{D_L}{rS\theta_s}$$ for $D_L > d_e$, and

Equation 42 $$t = \frac{d_e}{rS\theta_s}$$ for $D_L < d_e$.

EXAMPLE 35. *Exposure of a Scanning Helium-Neon Laser System.*

Find the exposure of a scanning helium-neon laser system having the following parameters: a = 0.1 cm, ϕ = 5 mrad, Φ = 5 mW, θ_s = 0.1 rad, S = 30 s^{-1}, and the intrabeam viewing distance r = 200 cm.

Solution. The beam diameter D_L is—

$$D_L = \sqrt{a^2 + (r\phi)^2} = \sqrt{0.01 + 1} = 1.0 \text{ cm}$$

Since D_L (1.0 cm) > d_e (0.7 cm), equation 39 and 41 are applied. The PRF at the eye is 30 pulses per second and the exposure time for a single pulse is—

$$t = \frac{D_L}{rS\theta_s} = \frac{1.0 \text{ cm}}{(200 \text{ cm})(30 \text{ s}^{-1})(0.1 \text{ rad})}$$

$$t = 1.68 \times 10^{-3} \text{s}$$

From equation 39, the radiant exposure per pulse is—

$$H = \frac{(1.27)(5 \times 10^{-3} \text{ W})(1)}{(1.005 \text{ cm})(200 \text{ cm})(30 \text{ s}^{-1})(0.1 \text{ rad})}$$

$$H = 1.05 \times 10^{-5} \text{ J} \cdot \text{cm}^{-2}$$

The MPE_{SP}, where a single pulse lasts 1.68 ms, from table E–1 is—

$$MPE_{SP} = 1.8\left(1.68\times10^{-3}\right)^{0.75}\times10^{-3}\,\mathrm{J\cdot cm^{-2}} = 1.5\times10^{-5}\,\mathrm{J\cdot cm^{-2}}$$

A single pulse does not exceed MPE_{SP}.

For rule 2, the total radiant exposure for T_{max} must be compared to the MPE for T_{max}. The total radiant exposure (H_{tot}) is the product of the radiant exposure for a single pulse and the number of pulses during the exposure. Since the laser wavelength is in the visible portion of the spectrum, an exposure duration of 0.25 s may be used. The number of pulses in the exposure is—

$$n = F_{eff}\times T = 30\ \mathrm{s^{-1}}\times 0.25\ \mathrm{s} \approx 8\ \text{pulses}$$

This cumulative radiant exposure must be compared to the MPE for a pulse train (MPE_{train}) of 0.25 s.

$$H_{tot} = n\left(H/pulse\right)\mathrm{J\cdot cm^{-2}} = 8\left(1.05\times10^{-5}\right)\mathrm{J\cdot cm^{-2}}$$

$$H_{tot} = 8.4\times10^{-5}\,\mathrm{J\cdot cm^{-2}}$$

$$MPE_{TRAIN} = 2.5\times10^{-3}\times0.25 = 6.25\times10^{-4}\,\mathrm{J\cdot cm^{-2}}$$

For rule 2, the MPE is not exceeded. For rule 3, a correction factor to the single pulse MPE is used.

From equation 2—

$$MPE/pulse = \left(MPE_{SP}\right)\cdot C_P = \left(MPE_{SP}\right)\cdot n^{-0.25}$$

$$MPE/pulse = \left(1.5\times10^{-5}\right)\cdot\left(8\right)^{-0.25} = 8.9\times10^{-6}\,\mathrm{J\cdot cm^{-2}}$$

This *MPE/pulse* is compared to the radiant exposure per pulse of 10 $\mu J\cdot cm^{-2}$. The exposure is slightly above the MPE rule 3, making this laser unsafe for momentary viewing.

B-20. Laser protective eyewear

When engineering and/or administrative controls cannot eliminate the potential for an accidental hazardous exposure, laser eye protection may be required. Optical density (D_λ), is a term that specifies the amount of protection afforded by a particular set of eye protection at a particular wavelength. It is defined as the base ten logarithm of the reciprocal of the transmittance.

Equation 43 $$D_\lambda = \log_{10}\left[\frac{1}{\tau_\lambda}\right]$$

The ratio of the MPE to the irradiance (E) or radiant exposure (H) at the laser exit port, at a given distance from the exit port, or at the exit pupil for a magnifying optic determines the necessary protective transmission for a laser protective filter. The OD in terms of MPE is—

Equation 44 $$D_\lambda = \log\left[\frac{E}{MPE}\right] or = \log\left[\frac{H}{MPE}\right]$$

EXAMPLE 36. *Alexandrite Laser.*

Calculate the worst-case OD required for protection against an alexandrite laser used in a hospital for tattoo removal. The laser operates at 755 nm, has a single pulse output energy of 20 mJ, a pulse width of 50 ns, and the beam diameter is 6 mm.

Solution. The MPE from table E–1 is—

$$MPE_{SP} = 5 \cdot C_A \times 10^{-7}\,\mathrm{J \cdot cm^{-2}}$$

From table E-3, C_A at 755 nm is 1.29. This results in an MPE of 6.44×10^{-7} $\mathrm{J{\cdot}cm^{-2}}$. The worst-case OD is determined by averaging the radiant energy at the laser exit port over the limiting aperture for that wavelength regardless of the beam diameter. At 755 nm, the limiting aperture is 0.7 cm.

$$H = \frac{20\times10^{-3}\,\mathrm{J}}{0.385\,\mathrm{cm}^2} = 5.19\times10^{-2}\,\mathrm{J\cdot cm^{-2}}.$$

Therefore, the worst-case OD is—

$$D_\lambda = \log\frac{5.19\times10^{-2}}{6.44\times10^{-7}} = 4.91$$

EXAMPLE 37. *Minimum Optical Density (0.5 J, Q-switched, Nd:YAG rangefinder).*

Calculate the minimum OD required for unaided viewing from a 0.5 J, Q-switched, Nd:YAG rangefinder at a distance of 1 km from the laser exit port. The laser has an initial beam diameter of 1 cm, a divergence of 1 mrad, and a pulse width of 20 ns.

Solution. At a distance of 1 km, the beam diameter is—

$$D_L = \sqrt{1.0^2 + \left(1\times10^5\right)^2\left(1\times10^{-3}\right)^2} = 100\,\text{cm}$$

When the laser beam is larger than the limiting aperture (7 mm for 1064 nm) and optical aids are not used, the necessary OD is simply the log of the ratio of the radiant exposure or irradiance at the given distance to the MPE. If, at 1 km, the beam diameter were smaller than the limiting aperture, then the method shown in the previous example would be used to calculate the OD. The radiant exposure, at 1 km, from equation 6 is—

$$H = \frac{4(0.5\,\text{J})}{\pi 100^2} = 6.35\times10^{-5}\ \text{J}\cdot\text{cm}^{-2}$$

The MPE from table E–1 is 5×10^{-6} J·cm^{-2}. The OD is—

$$D_\lambda = \log\left[\frac{H}{MPE}\right]$$

$$D_\lambda = \log\left[\frac{6.35\times10^{-5}}{5\times10^{-6}}\right] = 1.1$$

Due to the possibility of atmospheric turbulence causing non-uniformities in the beam, 1 OD unit should be added to the calculated OD, resulting in a final OD of 2.1. Intrabeam viewing of a laser through optical aids generally increases the potential hazard when compared to unaided intrabeam viewing. Lasers operating at wavelengths greater than 2.8 mm generally are not transmitted by optical instruments due to characteristics of the glass. If OD calculations are made where the laser beam diameter is smaller than the entrance aperture diameter of the optical aid, then the method used in example 36 is used to calculate the OD.

EXAMPLE 38. *Minimum Optical Density (0.1 W tactical laser pointer).*

Calculate the minimum OD necessary to safely view a 0.1 W tactical laser pointer operating at 860 nm, at a range of 75 m. The initial beam diameter of the laser is 7 mm, and it has a divergence of 2 mrad. Assume the laser is being viewed with 7×50 binoculars that transmit 70 percent at the laser wavelength.

Solution. The beam diameter (D_L) and the irradiance (E) at 75 m is—

$$D_L = 0.7\,\text{cm} + (7500\,\text{cm})\cdot\left(2\times10^{-3}\right) \approx 16\,\text{cm}$$

$$H = \frac{1.27(0.1\,\mathrm{W})}{(16\,\mathrm{cm})^2} = 4.96 \times 10^{-4}\,\mathrm{W \cdot cm^{-2}} \approx 0.5\,\mathrm{mW \cdot cm^{-2}}$$

The MPE for a 10 s exposure, C_A mW·cm^{-2} = 2.1 × 10^{-3} W·cm^{-2}, is not exceeded at 75 m for unaided viewing. When optics is used, the optical gain (equation 34) of the binoculars must be considered.

$$G_{eff} = \tau_\lambda \frac{[\min(D_c, D_L)]^2}{D_f^2}$$

$$G_{eff} = \frac{(0.7)(4.9\,\mathrm{cm})^2}{(0.7\,\mathrm{cm})^2} = 34$$

The irradiance through the binoculars is simply 34 × 0.5 mW·cm^{-2} = 17 mW·cm^{-2}. This irradiance at the exit aperture of the binoculars must be compared with the MPE.

$$D_\lambda = \log\left[\frac{17}{2.1}\right]$$

$$D_\lambda = 0.91$$

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APPENDIX C

MEDICAL SURVEILLANCE

C–1. Introduction

a. The U.S. Army laser medical surveillance program is the ongoing, systematic collection, analysis, and interpretation of data essential to the planning, implementation, and evaluation of Army force health. Medical surveillance as implemented in this document refers to occupational medical surveillance, which is the monitoring applied to individual workers based on actual or presumed workplace exposures.

b. Medical surveillance is required for personnel working with Class 3b and Class 4 lasers and laser systems and is not a requirement for those personnel working with Class 1, Class 2, or Class 3a lasers or laser systems. See DA Pam 40–506 for detailed information.

C–2. Employment status and vision screening

a. Preemployment vision screenings. Performed at or just prior to employment to provide a baseline visual performance measurement and to assist in appropriate job placement. This is part of the preemployment physical.

b. Preplacement vision screenings. Performed when there is a major change of job duties or change to a new job that has a significant change of duties. Permanent change of station with no significant change of duties does not require an additional screening.

c. Termination vision screenings. Performed at or just prior to separation from government employment for employees who have worked in an eye-hazardous job or area.

d. Vision screening results. Results will be placed in the individual's health record. The record will reflect the purpose of the vision screening, the results, and any required follow up. The record should document the following:

(1) *Demographic information*—

(a) Employee's name.

(b) Social security number.

(c) Organization or unit.

(d) Duty position or occupation.

(e) Job vision standard.

(f) Eye protection requirement (if any).

(g) Reason for screening (pre-employment, preplacement, problems, or termination).

(2) *Clinical information*—

(a) Vision screening test results.

(b) Evaluation of screening results.

(c) Disposition (such as, cleared for duty, refer for further evaluation, or release).

C–3. Classification of laser workers

a. Laser workers. Laser workers are those individuals who routinely work in a laser environment having Class 3b and Class 4 lasers and, therefore, have a higher risk of accidental overexposure. Laser workers include those who regularly perform laser research, development, testing and evaluation; individuals who work with or near medical lasers found in operating rooms; and workers who perform routine laser maintenance. Laser workers have a moderate to high risk potential for laser injury.

b. Incidental laser workers. Incidental laser workers are those individuals whose work makes it possible, but unlikely, that they will be exposed to laser energy that could damage the eye. Incidental workers include operators of fielded laser equipment, individuals who oversee laser use on approved laser ranges, and Soldiers who participate in Force-on-Force laser training exercises. Incidental laser workers are considered to have low risk potential for laser injury. (Note: Laser workers and incidental laser workers are essentially equivalent to laser personnel and incidental personnel as defined in ANSI Z136.1 and laser personnel and incidental healthcare personnel as defined in ANSI Z136.3.)

C–4. Laser medical surveillance/assessment

Medical assessments will be performed for individuals involved with lasers per ANSI Z136.1 and Z136.3.

a. Laser workers (laser personnel). Laser workers will have an ocular and visual history, visual acuity (VA), color vision test, and a central visual fields test (via Amsler Grid or similar macular integrity test) at preplacement and termination. VA, color vision test, and central field tests are to be performed on each eye separately. If the worker’s distance VA is 20/20 in each eye, color vision test is normal, central visual fields normal via Amsler grid test or similar macular integrity test, and medical history is normal for the eyes, no further examination is required. Any deviation from the acceptable normals will be evaluated to determine the reason. This may be done by ocular funduscopic examination or other tests as deemed appropriate by the eye care professional.

b. Incidental laser personnel (incidental healthcare personnel). Incidental laser workers will have each eye screened for VA. This screening is part of the pre-employment physical.

C–5. Protective measures required

a. Laser workers are required to wear wavelength-specific laser-protective goggles whenever a Class 3b or Class 4 laser is in use. In addition, the OD of the filtering lenses must be capable of reducing the power of the incident laser beam to a level safe to view. Refer to MIL–HDBK–828A to find the wavelength and OD requirements for laser eye protection when using military laser equipment. In addition to PPE, laser work areas should be set up according to procedures outlined in ANSI Z136.1 unless the LSO establishes other criterion based on the specific laser and laser operation.

b. Incidental laser workers do not require laser protective goggles unless the LSO, the installation safety officer, or the installation Vision Conservation and Readiness Officer deem it necessary. (Note: Filters and some materials used in laser protective equipment tend to darken and crack with time (that is, long-term storage)). They also may provide less protection after repeated exposure to laser emission. The LSO or a designated representative should inspect the equipment periodically for integrity of the protective devices and lenses as well as the ability to filter the laser radiation (ANSI Z136.1)).

C–6. Emergency care for laser injury

a. Any soldier or DOD employee with a confirmed or suspected, unprotected exposure to a Class 3b or more powerful laser will have a diagnostic vision examination as soon as possible (no later than 24 hours) by an optometrist or ophthalmologist at the nearest military treatment facility (MTF). Documentation of the injury will include a history of the event and a thorough vision and ocular examination. The examination is required to include ocular history, distance VA, Amsler grid (or similar central visual field) test, slit lamp examination, ocular fundus evaluation through dilated pupil, ocular fundus photographs that depict the extent of injury or lack of injury, and photographs of any external or anterior segment injury.

b. If ophthalmic photographic capabilities are not available, then a detailed representation of the finding may be hand-drawn or the patient will be referred to the nearest MTF (or authorized local civilian provider) having such capabilities. Individuals with confirmed exposure will be examined by a retinal specialist.

C–7. Reporting

a. Once the optometrist or ophthalmologist suspects or confirms an acute laser overexposure incident, he/she will notify—

(1) The division/installation LSO.

(2) The division/installation RSO.

(3) The Tri-Service Laser Incident Hotline (DSN 240–4784 or commercial (210) 536–4784 or 800–473–3549) (email: laser.safety@hedo.brooks.af.mil).

(4) The USACHPPM LORP (DSN 584–3932/2331 or commercial (410)-436-3932/2331 or 800-222-9698) (e-mail: laserincident@amedd.army.mil).

(5) The USACHPPM Tri-service Vision Conservation and Readiness Program (TVCRP) Manager (DSN 584–2714 or commercial (410) 436–2714) (e-mail: laserincident@amedd.army.mil). After normal duty hours, contact the USACHPPM personnel via the staff duty officer (DSN 584–4375 or commercial (410) 436–4375 or 800–222–9698).

b. Information to be reported will include—

(1) Patient name, grade, and social security number.

(2) Unit name.

(3) Hospital providing care and registration number.

(4) Exposure date and source.

(5) Duty being performed at the time of the incident.

(6) Summary of symptoms and evaluation.

(7) Any follow-up information.

c. The installation RSO, with the help of the safety office, will secure the laser in question. (Note: Do not send the laser equipment to maintenance for repairs.) The USACHPPM LORP will initiate a technical evaluation of the incident and of the laser equipment involved and will render a technical report as soon as possible after the incident. The USAMRD–WRAIR Ocular

Hazards Division, in cooperation with the USACHPPM TVCRP, will coordinate the initial and follow-up care of the patient and will render a report on the patient's status and prognosis. The USACHPPM TVCRP Manager maintains the Laser Accident and Incident Registry and will forward copies of the reports to the USAMRD–WRAIR Ocular Hazards Division. See table C–1 and figure C–1 for information on laser-induced injuries.

Table C–1
Symptoms, signs, diagnosis, and treatment of laser-induced injuries[1]

Symptoms (Reported by patient)	Signs (Findings on examination)	Diagnosis (and likely laser etiology)	Treatment and Management
Skin and Anterior Eye Injuries			
Reduction in vision. Pain in eye, eyes tender. Red or warm face or skin.	White or hazy cornea. Conjunctival inflammation. Facial or skin erythema.	Mid-moderate corneal and/or skin burn. (Infrared laser, intermediate dose.)	If eye perforation is not suspected, apply topical antibiotics (ointment). Patch. Systemic antibiotics and pain medication.[2]
Profound loss of vision. Severe pain in eyes. Burning sensation of face or skin.	Corneal ulceration or loss of corneal tissue. Perforation of globe. Skin burn.	Severe corneal and/or skin burn. (Infrared laser, high dose.)	Needs physician/physician assistant[3] evaluation. Evacuate as appropriate.
Retinal Injuries			
Temporary loss of vision. Bright light experience. No pain.	External exam: normal. Internal exam: normal.	Glare, dazzle, or flash-blindness. (Low-dose laser.)	None. Return to duty.
No or slight visual impairment. Dark spot in field of vision.	External exam: normal. Internal exam: non-foveal retinal lesion(s).	Small non-foveal, retinal burn with no or minimal hemorrhage (visible or near-infrared laser, low to medium dose).	None. Return to duty if able to function.
Vision impaired. Large dark spot at or near center of vision.	External exam: normal. Internal exam: foveal retinal lesion(s).	Peri-foveal retinal burn, and/or hemorrhage (visible or near-infrared laser, medium dose).	Evacuate. Needs physician/physician assistant evaluation.
Severe visual impairment. Large dark spot at or near center of vision. Large floating objects in eye. May see blood.	External exam: normal. Internal exam: foveal retinal lesion(s) that may be obscured by vitreous hemorrhage.	Foveal retinal burn, with vitreous or subretinal hemorrhage (visible or near-infrared laser, high dose).	Evacuate. Needs physician/physician assistant evaluation.[2]

Notes:
[1] Reference: FM 8–50
[2] Oral aspirin or intramuscular analgesics may be used as needed. Topical anesthetics, such as tetracaine, are never prescribed but may be used on a one-time basis only to aid examination. Repeated use of topical anesthetics may predispose to further corneal injury.
[3] The optometrist at the Main Support Medical Company may be consulted on questionable cases.

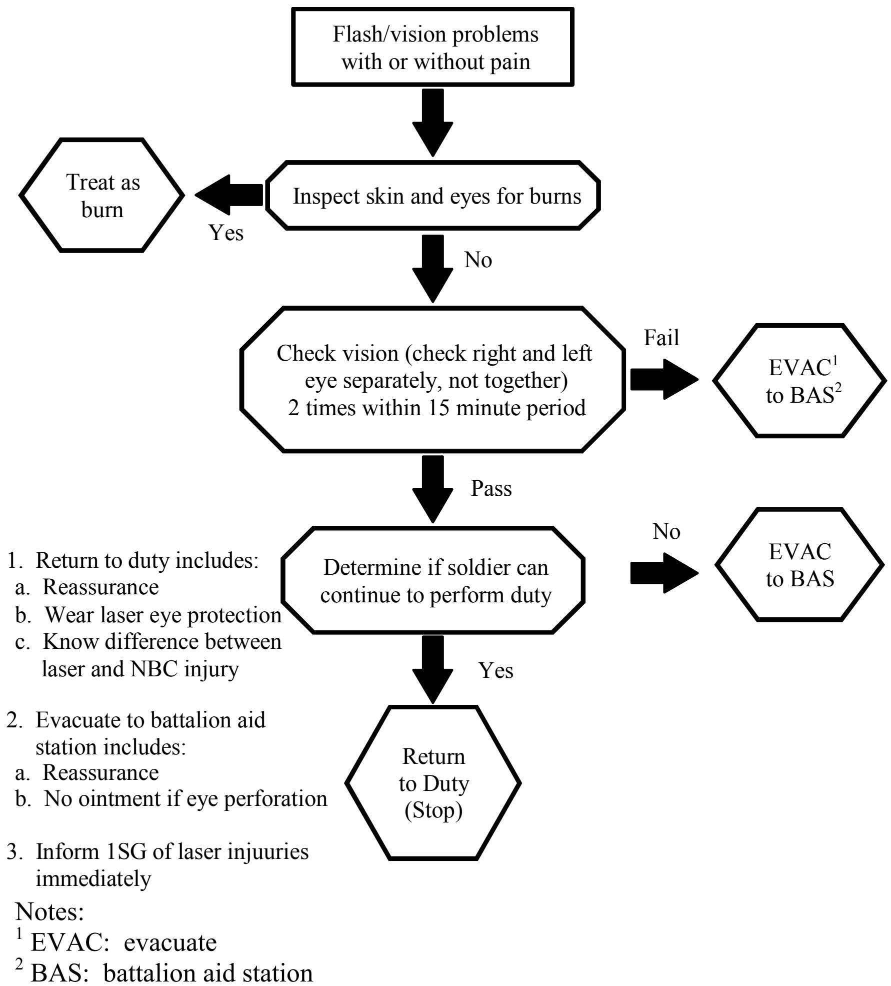

Figure C–1. Laser injury evaluation matrix

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APPENDIX D

SAMPLE SAFETY GUIDELINES

D–1. Introduction
The following information contains proposed guidelines to ensure that safety precautions are followed, adequate surveillance is provided, required protective eyewear is worn, and communication with personnel is maintained within established target areas. Each guidelines is a stand-alone document, and it is advisable to implement these guidelines as SOPs.

D–2. Scope
The LRSO/LRSNCO should refer to these guidelines to ensure that all personnel are thoroughly instructed on safety precautions.

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D–3. Safety guidelines for ocular safety in healthcare facilities

a. Purpose. To prevent ocular injuries to patients receiving laser treatment or to healthcare personnel (HCP) working with Class 3b and Class 4 lasers.

b. Policy. Within the nominal hazard zone (NHZ), all personnel will adhere to appropriate eye protection procedures during all laser applications. Under some conditions, the NHZ may occupy the entire room in which the laser procedure is performed. Under those conditions, the ocular safety procedures listed below apply to the entire room. Service personnel, biomedical technicians, and those involved in demonstrations of equipment will follow all ocular safety procedures whenever a laser is in operation in the facility.

c. Procedures.

(1) Appropriate eyewear will be worn by all personnel in the NHZ while the laser is in operation. Appropriate eyewear consists of glasses or goggles of sufficient optical density to prevent ocular damage at the laser wavelength in use. Exception to this is the operator looking through an attached microscope with a lens that has the appropriate optical density for the laser in use.

(2) Prior to use, the operator and ancillary personnel will be responsible for selecting and examining eyewear for comfort, proper fit, and presence of labels describing both wavelength and proper optical density.

(3) If eyewear is damaged, it must not be worn; a report must be made to the Laser Safety Officer.

(4) Contact lenses are not acceptable as protective eyewear. Prescription lens wearers must use appropriate laser safety eyewear.

(5) All goggles must have side shields to protect from peripheral injury and impact.

(6) Any articulated arm that is not shuttered must be capped when not connected to the hand piece or the operating microscope.

(7) The laser system must be placed in standby mode when delivery optics is moved away from the target.

(8) Patients will be fitted with appropriately labeled eyewear or have their eyes covered with wet cloth pads or towels. Metal or dry materials will be placed on the patient's face or eyes only when indicated.

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D–4. Safety guidelines for multiple integrated laser engagement system and related optical equipment for maintenance workers

a. Warning.

(1) Laser training devices, such as Multiple Integrated Laser Engagement System (MILES) or the Air to Ground Engagement System/Air Defense System (AGES/AD), present an optical viewing hazard even though the laser emission is invisible. These devices do not present as serious a hazard as laser rangefinders and designators, which can produce irreparable blindness from one accidental exposure. However, exposure to the direct output from the laser within a few meters exceeds currently established maximum permissible exposures (MPEs) for laser devices.

(2) Although immediate blindness would be unlikely from these MILES devices and other training systems, any possibility of potential injury involving the soldiers' eyes should be avoided. During training, checkout, or maintenance, the MILES or AGES/AD devices could produce an exposure exceeding the MPE if the devices are used by persons unaware of the hazards or if the devices are deliberately misused.

b. Training Procedures. The following steps should be taken to prevent overexposure to the laser energy:

(1) Provide safety training to any user of the MILES or AGES/AD equipment or personnel required to activate the transmitters during checkout or maintenance. The content of the training should include the material contained in this guideline.

(2) Never intentionally fire any hand-held weapon system at a person's face within 10 meters (m) during a training exercise.

(3) Never point and fire any large-gun MILES device, such as a tank gun simulator or tube launched, optically tracked, wire guided (TOW) missile, at anyone's face within 10 m during a training exercise.

(4) Goggles are recommended for users if small arms MILES devices are used with firing cables rather than blank activated.

c. General Information.

(1) The MILES transmitters emit a beam of infrared light pulses in a coded sequence. The energy per pulse and pulse codes determine the effectiveness of each weapon type and distinguish between a hit, kill, or near-miss. The beams are small and well collimated to allow use over extended distances. Detector belts located on vehicles and individuals respond to the infrared pulses and produce either an audible or visual indication of detection. Optical hazards from MILES devices are limited to eye exposure to the direct beam or from the beam deflected by a mirror. Diffuse or specular reflections from ordinary glass or other surfaces are not hazardous.

(2) Most MILES devices have a nominal ocular hazard distance (NOHD) of 10 m or less. A few have an increased hazard distance when binoculars are used to view the laser from within the direct beam. Laser protective eyewear should only be used when administrative controls are inadequate. Almost all MILES devices have a hazard classification of 3a or less. Some MILES devices are Class 1 and do not pose an eye hazard. Class 3a devices exceed the Class 1 accessible emission limit by no more than 5 times.

(3) The beam from some of the small arms transmitters (SATs) is slightly focused. Therefore, the hazard at 2 or 3 m from the device may be greater than at the exit port since most of the emitted energy could enter an individual's pupil. Some airborne systems may exceed the MPE by 10 times or more close to the laser exit port. The output energy per pulse varies between individual devices due to system requirements.

(4) When the MILES transmitters are mounted to hand-held weapons and are used with blank ammunition, a hazard exists a few meters along the line of sight from the wadding. Hazards from MILES devices are based on a 10-second exposure duration. A shorter exposure duration lessens the hazard but does not eliminate it. Movement of the weapon system immediately after firing would prevent the laser from delivering all the laser pulses fired to a person's eye. Large guns generally use weapon effects simulators in addition to MILES, and the beams are often above normal eye level, thus, reducing the injury potential. Since an exposure exceeding the MPE would be unlikely during a training exercise, the MILES systems were deemed "safe for field use." Laser goggles were not deemed necessary for field training.

(5) In 1986, the SAT for the M16 was redesigned for a smaller size, lower-energy emission, and the addition of boresight controls on the MILES device. The hazards from that design approach but do not exceed the MPE. Several styles, models, and generations of the SAT are currently in use, most of which exceed the MPE within a few meters of the device (usually no more than 10 m for unaided viewing). Therefore, caution is recommended when training at close engagement distances.

d. Maintenance Procedures.

(1) Develop a standing operating procedure (SOP) for all transmitter maintenance tasks; ensure that maintenance personnel are familiar with it and follow the SOP.

(2) Do not allow personnel in the maintenance area who are unaware of the MILES optical hazards.

(3) Ensure that personnel maintaining equipment are aware that the direct beams from MILES devices are hazardous within 10 m.

(4) Never point an operational MILES device at your face or the face of another person.

(5) Position the MILES transmitter so that the beam is horizontal, below eye level, and terminated into a diffuse surface before turning the device on. This precaution is especially important for malfunctioning devices.

(6) Make sure that the MILES transmitter is off before transporting it to a new location.

(7) Use laser protective eyewear when facial exposure to the direct beam cannot be avoided. Laser protective goggles with an optical density of at least 2.0 at 905 nanometers or a 3-millimeter thickness of Schott KG–3 glass is sufficient.

D–5. Safety guidelines for training with portable fire control lasers

(Note: This guideline should be tailored for individual applications and unit requirements.)

a. Warning. Laser rangefinders and designators can cause irreparable eye injury and possible blindness if used improperly. Exposure of the eye to either the direct beam or a beam reflected from a flat mirror-like surface could cause an injury at a great distance.

b. Reference. Army Regulation (AR) 385–63, *Range Safety*.

c. Control Measures. The following control measures will prevent hazardous exposure when training operators with portable fire control lasers in one-sided exercise:

(1) Laser operators shall periodically read and always follow this safety guideline.

(2) Laser operators shall never point the laser at any unprotected personnel or flat, mirror-like surfaces such as glass.

(3) Laser operators should operate only on laser-approved ranges established according to AR 385-63.

(4) The laser will not be operated or experimented with outside the range area unless it is specifically authorized. The laser exit port will be covered by an opaque dust cover and will be disabled by removal of the battery when the laser is located outside the range area.

(5) Positively identify the target and buffer areas prior to laser operations.

(6) Laser eye protection is not required for laser operators even when viewing the target area with binoculars. However, operators should never enter into the laser target area without appropriate laser eye protection. Such eye protection should have curved lenses.

(7) No special precautions are necessary for firing during rain, fog or snow fall. Certain ranges may be closed for operation if water begins ponding either on the open ground or on snow.

(8) Laser operators should report immediately to their supervisor any suspected injury or defective equipment (such as, misalignment of the laser beam with the pointing telescope) so that appropriate action may be taken.

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D–6. Safety guidelines for training with tactical laser pointers

(Note: This guideline should be tailored for individual applications and unit requirements.)

a. Warning. Class 3b Tactical Laser Pointers (such as the Ground Commander's Pointer (GCP) (Airborne Infrared Multipurpose–1), Air Commander Pointer, and AN/PEQ-2/2A) can cause eye damage if used improperly. Exposure of the eye to either the direct beam or a beam reflected from a flat mirror-like surface could cause an injury even at a great distance.

(1) Note 1: The AN/PAQ–4 tactical laser pointer, in A, B, or C versions, is categorized as a Class 1 system and does not pose a hazard under any viewing condition.

(2) Note 2: Class 4 pointing lasers should not be used even in combat.

(3) Note 3: This guideline does not apply to commercially available classroom visible laser pointers.

b. Control Measures. The following control measures will minimize the chance of a hazardous exposure when operating tactical laser pointers:

(1) Equipment should only be operated by personnel who have received proper training for the operation of the laser. Refer to operator's manual for startup and firing procedures.

(2) Laser operators shall periodically read and always follow this safety guideline.

(3) Operate only in laser-approved areas.

(4) The laser will not be operated or experimented with outside the laser-approved area unless it is specifically authorized. The laser exit port will be covered by an opaque dust cover and/or the laser disabled by removal of the battery when the laser is located outside the laser-approved area.

(5) Positively identify the target and buffer areas prior to laser operations.

(6) Generally, laser eye protection is not required for laser operators even when viewing the target area with binoculars.

(7) Glass-like surfaces, such as an aircraft canopy, can reflect 10 percent or more of the laser energy. For example, high-power tactical pointers, such as 100 milliWatt (mW) models of the GCP, are considered hazardous at 10 percent of the total laser power (approximately 4-8 mW into the eye is considered the threshold for ocular injury). However, the risk of a laser eye injury to the operator while directing the laser beam through an aircraft canopy is considered small and is nonexistent with Class 1 or Class 3a lasers.

(8) Due to the geometry of the devices, night vision goggles (NVGs) should not be relied upon as a substitute for laser eye protection. With certain NVG devices, it is possible to be potentially exposed to a hazardous laser beam from an indirect line of site when the NVG devices do not fit snugly against the face.

(9) Do not illuminate unprotected personnel. However, under certain circumstances such as Force-on-Force training, it may be authorized to illuminate individuals or vehicles, but these individuals should be informed they might be lased. Individuals should never enter into the laser target area (within the nominal ocular hazard distance) without appropriate laser eye protection. Laser eye protection should be chosen to reduce the laser exposure to Class 1 levels during training and Class 3a levels during tactical situations. Eye protection for Class 3b and Class 4 lasers shall have curved lenses to prevent hazardous back reflections from the eye protectors.

(10) The output power of laser-aiming devices shall be limited to preclude operation above Class 3a during Force-on-Force training. Any Class 3b product must be attenuated or otherwise controlled to limit emission to Class 3a or below (sometimes referred to as the training mode).

Methods to reduce emission include removable attenuation filters and mode selector switches; however, attenuation control methods should require a special tool to deactivate the attenuation. Common tools, such as a screwdriver, are not acceptable for this purpose. Additionally, the laser device should clearly indicate that the training mode is selected.

(11) No special precautions are necessary for firing during rain, fog, or snowfall.

(12) Report immediately any suspected injury or defective equipment to your chain of command so that appropriate action may be taken.

D–7. Safety guidelines for maintenance shop operation of fire control lasers
(Note: This guideline should be tailored for individual applications and unit requirements.)

a. Warning. Laser rangefinders and designators can cause irreparable eye injury and blindness if used improperly. Exposure of the eye to either the direct beam or a beam reflected from a flat mirror-like surface could cause an injury to the unprotected eye. Class 4 lasers may also pose a potential hazard when viewing a diffuse reflection of the beam and may also pose a skin hazard.

*b. Control Measures***.** The following control measures will prevent hazardous exposure during laser operations in the maintenance shop:

(1) Maintenance personnel shall periodically read and always follow this safety guideline.

(2) Only those operations authorized in appropriate maintenance manuals shall be permitted.

(3) Laser operators shall never direct the laser at unprotected personnel.

(4) Laser operators shall wear laser protective eyewear whenever the laser is operated with an unenclosed beam and then use a countdown procedure.

(5) Laser operators shall operate the laser from within an approved area that is closed such that no line-of-sight exists to unprotected personnel outside the area. The laser exit port will be covered by an opaque dust cover, and the battery will be removed from the device when it is located outside the closed area unless it is specifically authorized.

(6) Prior to laser operations, maintenance personnel shall complete the following checklist:

(a) Periodically test door electrical interlock switches at entrances. It is not a good safety practice to lock access doors.

(b) Select appropriate laser protective eyewear. Ensure that eye protection is marked with its protective characteristics.

(c) Test warning lights or alarms to the closed area.

(d) Post a warning sign at entrances to the closed area.

(e) Ensure that any other required safety devices are available.

(f) Ensure that beam path is clear of potentially reflective materials.

(7) A lens used to focus the laser beam of Class 3 and Class 4 lasers will increase the eye hazards from diffuse reflections and the skin hazards around the focal point.

(8) Report immediately to your supervisor any suspected injury or defective equipment so that appropriate action may be taken.

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D–8. Safety guidelines for laser operations

a. Purpose. This guideline prescribes the policies and procedures for laser operations.

b. Objective. To properly control the use of all laser operations except the Multiple Integrated Laser Engagement System (MILES) devices during training.

c. References.

(1) Technical Bulletin, Medical (TB MED) 524, *Control of Hazards to Health from Laser Radiation*.

(2) Military Standard (MIL–STD)–828A, *Laser Safety on Ranges and in Other Outdoors Areas*.

(3) Field Manual (FM) 8–50, *Preventive and Medical Management of Laser Injuries*.

d. Responsibilities.

(1) *Commander.* Commanders at all levels are responsible for ensuring strict compliance with good safety practices during laser operations. Commanders will—

(a) Appoint a Laser Range Safety Officer/Noncommissioned Officer (LRSO/NCO) who has successfully completed the Laser Safety Course provided by the Safety Office, Radiation Safety Officer (RSO), or Range Control Officer. This training should be updated as required by the RSO or Range Control Officer.

(b) Establish a written guideline.

(2) *LRSO/NCO.* The LRSO/NCO will—

(a) Be present at all times during laser operations.

(b) Inspect laser targets and target areas daily prior to laser operations commencing and after adverse weather conditions (that is, rain or ice storms). This inspection will ensure that there are no specular (reflective) objects on or around the target according to TB MED 524 and that no one is downrange without the appropriate protective equipment and communication. The Range Control Officer may decide to record a log of these inspections.

(c) Ensure that all signs and barricades are properly positioned according to range control guidance at least 24 hours prior to operations.

(d) Ensure that a safety briefing is given prior to laser operations.

(e) Ensure that a copy of the range regulation and live-fire scenario is available at the range site, if applicable.

(f) Ensure that any suspected or actual laser casualty receives immediate treatment at a medical facility (that is, unit has 24 hours to get suspected casualty to medical facility) according to TB MED 524.

(g) Ensure that no one is allowed downrange unless they have the proper equipment and communication.

(h) Ensure that the laser surface danger zone is accurate.

(i) Be familiar with all appropriate publications concerning lasers, in particular TB MED 524 and MIL–HDBK–828A.

(j) Depending on how local regulation stipulates, coordinate with the Range Control Officer concerning Notice to Airman and announcements in the Daily Bulletin.

(k) Coordinate with safety office prior to start of laser operation

(3) *Units.* Units conducting laser operations will—

(a) Ensure that the exit port of the laser is covered by an opaque cover when not operational or when traveling to and from ranges.

(b) Ensure that laser operators have positively identified the target prior to lasing.

(c) Ensure that the use of optical devices is coordinated with the LRSO/NCO and Range Control Officer.

(d) Coordinate with the Range Control Officer to ensure that other units on adjacent ranges are aware that laser operations are being conducted and that adjacent units do not use magnified optics to observe the laser operations.

e. Additional laser Information.

(1) The laser system, except for its inability to penetrate targets, will be treated as a direct fire, line-of-sight weapon such as a rifle or machine gun.

(2) The use of optical devices to observe the target during laser operations will not be permitted unless flat, specular surfaces have been removed from the target area or unless appropriate laser safety filters are placed in the optical train of the binoculars, telescope, or laser itself.

(3) All targets planned for laser engagement will be inspected by a qualified Laser Safety Officer (LSO) prior to initial use. Only targets and target areas approved by the LSO and Range Control Officer will be engaged with lasers. The LRSO/NCO will reinspect all approved targets and target areas prior to each day's operation and after adverse weather.

(4) First-aid will comply with FM 8–50.

Table D–1
Precautions/Danger areas for laser systems[1]

Laser System	Area T	Area S	NOHD	NOHD[2]	Static Buffer	Moving Buffer
AN/VVG-3[3] M1 Tank	0	60M	7K	35K	2 mils	5 mils
AN/GVS-5[4] (hand held)	0	200M	2.7K	13K	10 mils	Cannot use in training on the move.
TADS[5] (Apache)	0	200M	26K[1]	70K[2]	5 mils	5 mils
MMS[6] (OH-58D)	0	200M*	35K[1]	80K[2]	2-5 mils	5 mils
LAAT[7] (Cobra)	0	60M	5K[1]	30K[2]	2-5 mils	5 mils
AN/TVQ-2 G/VLLD[8] (designator)	0	60M	25K	80K	2 mils	Cannot use in training on the move.

Notes:
[1] Reference: MIL–HDBK-828A
[2] These distances may change and these distances are worst-case (multiple pulse)
[3] AN/VVG: Army Navy/Ground Vehicular, Visible Light, Fire Control
[4] AN/GVS: Army Navy/Ground, Visible Light, Detecting (range and bearing)
[5] TADS: Target Acquisition Designation Sight
[6] MMS: Mast-Mounted Sight
[7] LAAT: Laser Augmented Airborne Tube Launched, Optically Tracked, Wire Guided (TOW)
[8] G/VLLD: Ground/Vehicle Laser Locator Designator

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D–9. Safety guidelines for laser ranges

(Note: This guideline should be tailored for individual applications and unit requirements.)

a. Procedures.

(1) All personnel involved in a laser evaluation/exercise including laser operators, maintenance personnel, and range control personnel shall periodically read and always follow this safety guideline.

(2) Appropriate personnel shall ensure equipment is only operated by personnel who have received proper training for the operation of the laser.

(3) Appropriate personnel shall ensure that a laser range evaluation for a specific laser system or group of lasers has been conducted on the range being used.

b. References.

(1) American National Standards Institute (ANSI) Z136.1, *Safe Use of Lasers*.

(2) Military Standard (MIL–STD)–1425A, *Safety Design Requirements for Military Lasers and Associated Support Equipment*.

c. Laser Range Evaluation.

(1) *Test laser*. To evaluate a laser for use on a range, one must determine the hazard potential of the system by determining the following:

(a) Maximum permissible exposure (MPE) limits. MPEs as provided by ANSI Z136.1.

(b) Laser classification. Classify the laser using procedures in MIL STD 1425A to determine laser control measures that need to be implemented.

(c) Nominal ocular hazard distance (NOHD). Determine the distance from the operating laser to the point where the laser is no longer an eye hazard.

(d) Reflections. Determine if the laser is capable of producing hazardous specular and/or diffuse reflections.

(e) Optical density (OD). Determine the degree of protection required to reduce the incident laser energy to safe eye and skin levels.

(f) Optically aided viewing. Consider the possibility of personnel viewing the laser beam or a reflection from the beam with optical instruments such as binoculars. (Note: These types of devices can increase the degree of hazard to the eye significantly, thus, increasing the NOHD and necessary OD.)

(g) Atmospheric attenuation. Atmospheric attenuation can be quite high for lasers operating at ranges greater than 10 kilometers, reducing the NOHD considerably.

(h) Laser platform stability. The stability of the laser platform is needed to determine the pointing accuracy of the laser. Pointing accuracy determines the size of the buffer angle.

(2) *Range*. A range map, topographic map, and an air space map are required for a laser range evaluation.

(a) Range map. The range map is used to establish accurate distances to the target area and range boundaries. This map should also include the locations of targets and also items such as buildings and towers.

(b) Topographic map. This is important because it enables the test director to determine target elevations, as well as natural backstops such as hills that can be used to control the beam.

(c) Airspace map. This map includes airspace associated with the range having specific, possibly non-coincident lateral boundaries and a specific minimum and maximum altitude.

(d) Target and target area. The size, location, and type of targets to be fired at are important in determining the hazard zone.

(3) *Mission*. An evaluation must be completed for each type of laser used on the range. The laser operating mode (that is, air-to-ground, ground-to-ground, ship-to-target, and so forth) must be determined.

(4) *Laser surface danger zone (LSDZ).* The LSDZ (also called the buffered laser footprint) must be determined.

(5) *Laser-user-level instructions*. Utilizing the laser range safety evaluation, the Laser Safety Officer/Radiation Safety Officer will determine the necessary information to—

(a) Review and ensure that range safety regulations are current. Regulations should be developed or updated as necessary to take into account new laser systems, operating areas and targets.

(b) Develop a guideline for specific laser operations to inform laser users of the potential hazards from the laser device. A guideline should be prepared concerning procedures for a pre-sweep of the range before laser operation to ensure that unprotected personnel are not in the target area for such things as maintaining radio communications.

(c) Brief personnel involved in the laser operation to provide an understanding of the hazards of laser beams to humans and misconceptions about laser effects, principles of reflection and refraction of light, safety standards, and preparation of the range for laser use.

(d) Prescribe the personal protective equipment including the proper eye protection optical density requirements for worst-case exposure to the laser.

D–10. Safety guidelines for Force-on-Force training with tactical and training lasers

a. Purpose. To present and outline safety guidelines for the use of tactical and training lasers during Force-on-Force training.

b. Definitions.

(1) *Laser safety officer (LSO).* The LSO, unit level, is the individual in the laser user's chain of command who is responsible for all laser issues at the operational level. It includes but is not limited to: establishing unit specific laser regulations and procedures, ensuring compliance to the appropriate laser regulations and restrictions of the host facility that the appropriate operational and safety training for the laser device shall be used, and ensuring that all other unit related laser safety issues are addressed.

(2) *Nominal hazard zone (NHZ).* The NHZ is the designated region on the ground and in air space where laser radiation levels may exceed the maximum permissible exposure (MPE) level.

(3) *Nominal ocular hazard distance (NOHD).* The NOHD is the distance along the axis of the laser beam beyond which the irradiance ($W{\cdot}cm^{-2}$) or radiant exposure ($J{\cdot}cm^{-2}$) is not expected to exceed the appropriate MPE, that is, the safe distance from the laser. The NOHD–Magnifying (NOHD–M) is the NOHD when viewed with optical aids.

c. Procedures.

(1) *LSO, unit level*.

(a) The LSO shall—

1. Coordinate all laser operations through range control. In the event the training area is not managed by range control, coordination will be through the installation Radiation Safety Officer.
2. Be familiar with the particular devices or simulators, with respect to the laser hazard, being used during the operation or exercise.
3. Understand the principles of reflection and refraction of light.
4. Understand the hazards of laser beams to humans and misconceptions about laser effects.
5. Know applicable safety standards and operational control procedures applicable to the exercise or operation including but not limited to local range and installation regulations and procedures.
6. Ensure the range or training areas are prepared for laser use.
7. Brief applicable personnel on laser safety policy and procedure for the operation or exercise.

(b) The LSO personnel briefing shall include—

1. Instruction on particular devices or simulators with respect to the laser hazard.
2. Principles of reflection and refraction of light.
3. Hazards of laser beams to humans and misconceptions about laser effects.
4. Safety standards and/or operational control procedures.
5. Recognition of potentially unsafe range areas, training areas, or conditions applicable to laser use.

(2) *Class 4 and Class 3b lasers*. These lasers and laser systems shall not be used in Force-on-Force training unless the following minimum conditions are met and strictly adhered to. Also, Class 3a lasers and laser systems with an unaided NOHD greater than 15 meters (m) shall not be used in Force-on-Force training unless the following minimum conditions are met and strictly adhered to:

(a) Any Class 3B or Class 4 laser or laser system must be attenuated or otherwise controlled to limit emission to Class 3B or below (sometimes referred to as the training mode). Methods to reduce emission include removable attenuation filters and mode selector switches; however, attenuation control methods should require a special tool to deactivate the attenuation. Common tools, such as a screwdriver, are not acceptable for this purpose. Additionally, the laser device should clearly indicate that the training mode is selected. If, after beam attenuation, the unaided NOHD is greater than 15 m, the laser or laser system shall not be used in Force-on-Force training unless the following minimum conditions are met and strictly adhered to.

(1) The NHZ shall be controlled.

(2) Individuals should never operate within the NHZ or within the NOHD without appropriate laser eye protection.

(3) Eye protection for Class 3b and Class 4 lasers shall have curved lenses to prevent hazardous back-reflections from the eye protectors.

(4) Individuals shall be informed about the potential hazard.

(5) Individuals should not use optics within the NHZ or the NOHD–M when it is possible for the optics aperture to be lased and the optics do not protect the user against the lasers that are being employed.

(6) Other safety protocols or procedures may be applicable.

(b) If, after beam attenuation, the unaided NOHD is less than 15 m, review training requirements for Class 3a lasers in paragraph c (3).

(3) *Class 3a lasers*. These lasers and laser systems shall not be used in Force-on-Force training unless the unaided NOHD is less than 15 m and the minimum conditions listed below are met and strictly adhered to. Also, Class 3a lasers and laser systems with an unaided NOHD greater than 15 m shall not be used in Force-on-Force training unless the guidance given in paragraph c (2) are met and strictly adhered to.

(a) The output power of the laser devices shall be limited to preclude operation above Class 3a during Force-on-Force training. Methods to reduce emission include removable attenuation filters and mode selector switches; however, attenuation control methods should require a special tool to deactivate the attenuation. Common tools, such as a screwdriver, are not acceptable for this purpose. Additionally, the laser device should clearly indicate that the training mode is selected.

(b) Individuals shall have the appropriate knowledge about the potential hazard and shall be informed they may be lased.

(c) Do not illuminate unprotected personnel within the NOHD (that is, within 15 m). Individuals should never operate within the NHZ or within the NOHD without appropriate laser eye protection if they may be potentially lased.

(d) Individuals should not use optics within the NHZ, or the NOHD-M when it is possible for the optics aperture to be lased.

(e) Other safety protocols or procedures may be applicable.

(4) *Class 2 and Class 2a lasers.* These lasers and laser systems should not be used in Force-on-Force training unless the following minimum conditions are met and adhered to:

(a) Individuals should be appropriately knowledgeable about the potential hazard and should be informed they may be lased. Class 2 and Class 2a laser systems are considered a chronic

viewing hazard and should not be intentionally viewed. Brief exposure to a Class 2 or 2a laser will not cause permanent injury. Temporary conditions such as flashblindness, dazzle, or startle may occur.

(b) Other safety protocols or procedures may applicable.

(5) *Class 1 lasers.* These lasers and laser systems can be used in Force-on-Force training.

(a) Class 1 laser systems are safe under any viewing conditions. Exposure to a Class 1 laser will not cause permanent injury. Temporary conditions such as flashblindness, dazzle, or startle may occur.

(b) Other safety protocols or procedures may applicable.

(6) *Training situations*. Training situations, with respect to lasers, not addressed in this guidance should be referred to the respective service's Office of The Surgeon General representative for further guidance.

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D–11. Safety guidelines for controlled access to the laser room

a. Purpose. To define the area in which control measures shall be applied, and to describe the control measures necessary in order to maintain a safe environment for patients, and for healthcare personnel (HCP).

b. Policy. Class 3b and Class 4 lasers will be operated only in areas where traffic flow and compliance with all safety procedures can be monitored.

c. References.

(1) Technical Bulletin-Medical (TB MED) 524, *Occupational and Environmental Health Control of Hazards to Health from Laser Radiation*.

(2) American National Standards Institute (ANSI) Z136.3, *Safe Use of Lasers in Health Care Facilities*.

d. Procedures.

(1) Regulation Danger laser signs will be posted at eye level on all doors that access a room where a laser will be operated. These signs will state all required information as described in TB MED 524 or the ANSI Z136.3 standard and will be removed when the laser is not in use.

(2) Safety goggles labeled with the appropriate wavelength and optical density will be available at the entry where each door sign is posted.

(3) Glass windows will be covered with shades or filters of appropriate optical density whenever a fiberoptic laser system is operational.

(4) All safety procedures will be followed during service and demonstrations.

(5) No one will be allowed into a laser room unless properly authorized and protected.

(6) The laser should not be activated when it is necessary to open the door if the nominal hazard zone extends to doorway.

(7) Laser keys will be kept in a secured area and signed out only by those authorized to do so.

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D–12. Safety guidelines for laser operation and safety procedures during preoperative and operating room services

*a. Purpose***.** To provide guidelines to personnel assigned to the operating room that may operate or be in a surgical suite in which the laser may be used as part of the operative procedure the laser.

b. References.

(1) American National Standards Institute (ANSI) Standards, Z136.3, *Safe Use of Lasers in Health Care Facilities*.

(2) ANSI Standard Z35.1, *Specification for Accident Prevention Signs*.

(3) Association of Operating Room Nurses, *Standards and Recommended Practices: Recommended Practice for Laser Safety in the Practice Setting*, Denver, CO, AORN, Inc., 1998.

(4) Kohn, Mary L. and Atkinson, Lucy J., *Berry and Kohn's Introduction to Operating Room Technique*. Seventh Addition, N.Y., McGaw-Hill Co., 1992.

c. Procedures.

(1) *General information*.

(a) All staff members will follow established guidelines for laser use in the practice setting.

(b) Only qualified staff members will be responsible for the operation, management, and care of laser equipment.

(c) Only qualified staff members will be allowed to circulate or scrub during laser procedures.

(d) Prior to any laser procedure, the staff member assigned to the room will perform the procedures on the laser safety checklist.

(e) Each laser procedure will have a laser log sheet completed. The log sheet will be retained in the laser logbook maintained by the operating room Laser Safety Officer or other properly trained personnel.

(f) Traffic in the operating room suite in which the laser is being used will be kept to a minimum and restricted to necessary personnel.

(g) Plugs, cords, grounding mechanisms, and wall outlets will be checked for integrity prior to each procedure.

(h) The laser will be "test fired" and calibrated prior to the patient entering the suite.

(i) Laser keys will be kept in the operating room Lock Box when not in use.

(j) The laser will be placed in "Standby Mode" when not in use.

(k) The laser foot pedal will only be operated by the primary surgeon. No other foot pedals will be placed next to the laser foot pedal.

(l) Liquids will not be placed on the laser unit or near the foot pedal.

(2) *Laser signs*.

(a) "Laser In Use" signs will be placed prior to the start of the surgical procedure. Such things as sign dimensions, color, and letter size will be according to ANSI Standard Z35.1. All signs will specify the following information:

1. Universal laser symbol.
2. The word "DANGER".
3. Type of laser in use.
4. Power of highest setting and mode of delivery (that is, continuous, pulsed, or Q–switched).
5. Safeguards to avoid eye/skin exposure to direct/scattered radiation.

6. Identification of whether the beam is visible or invisible.

(b) The signs will be attached to each door, entry, and exit into the surgical suite.

(3) *Eyewear.*

(a) All personnel will have a baseline eye examination.

(b) All assigned personnel in the operating room where the laser will be in use are required to wear approved, properly fitted protective glasses or goggles. The glasses/goggles will be labeled with the wavelength in nanometers, have an optical density of 5 or greater, and have side shields.

1. Fluid or splash shields are not considered laser safe eye protection.

2. Contact lenses should not be worn as they may trap particulate matter.

(c) Eyewear will be inspected by wearer prior to and at the end of each use for defects in the optical coating of the lens and for mechanical integrity of the frame.

1. Eyewear will be cleaned according to manufacturer's recommendation after each procedure and placed in protective case.

2. Scratched, pitted, crazing, discolored, or cracked eyewear will be removed from the suite.

(d) Patient protection will be as follows:

1. The anesthetized patient will have his/her eyes closed, taped, and covered with saline moistened pads or gauze.

2. Patients undergoing local or regional anesthesia will wear appropriate protective eyewear while the laser is in use.

3. All patients will have corneal shields in place if procedure is on or near the eyelids.

(e) Eyewear will be available near entrance/exit areas for the room near the posted warning signs.

(f) The only exceptions to the wearing of protective eyewear will be if the surgeon is using the microscope with the rubber eye caps in the up position or he/she is wearing operative loops.

(4) *Mask.*

(a) All personnel will wear high filtration surgical masks during laser procedures.

(b) Masks will have a matrix dense enough to block laser plume material at least as small as .3 microns.

(5) *Smoke evacuation devices.*

(a) A smoke evacuation system will be used on plume generating laser evacuation procedures.

(b) A new filter and suction adapter will be used for each surgical procedure.

(6) *Prevention of burns.*

(a) All drapes used during laser procedures will be Class 1 fire retardant.

(b) Exposed tissue around the operative site will be protected with saline- or water-saturated material (that is, towels and sponges). The materials will be remoistened periodically.

(c) A fire extinguisher will be available in the room.

(d) Laser safe endotracheal tubes will be used during laser procedures.

(e) High levels of oxygen around the operative site will be avoided at all times.

(f) Flammable and combustible anesthetics, prep solutions, drying agents, ointments, plastics, and topical protectants will not be used. Examples include but are not limited to—

1. Benzoin swabs.

2. Collodian.

3. Alcohol-based prep solutions.

(g) Dulled, ebonized, or non-reflective anodized instruments will only be used near the operative site.

(h) The hairline will be moistened with a water soluble lubricant covered with a wet towel for procedures around the head.

(7) *Operation and testing of the laser*.

(a) Preoperative.

1. Obtain laser key from control area.
2. Obtain and post laser signs.
3. Obtain and check protective eyewear.
4. Obtain smoke evacuator filter and suction adapter.
5. Obtain smoke evacuator and check filter.
6. Position laser in proper area.
7. Check power cord for broken prongs, frayed, or exposed wires.
8. Check water hoses for cracks and/or leaks.
9. Obtain ancillary supplies and equipment according to surgeon preference card.
10. Remove flammable liquids from the laser area.
11. Secure the room.
12. Check the laser for proper functioning and calibration (see instruction sheet attached to laser).
13. Secure laser after performing checks; turn the laser OFF.
14. Check that the prepping agent, if used, is nonflammable.

(b) Checking beam alignment.

(1) Place a wet hand towel on a mayo tray.

(2) Set the helium neon beam intensity to the desired level, using the helium neon up/down keys at a continuous mode of illumination.

(3) Mark a cross on a moistened tongue depressor and place on the wet hand towel.

(4) Set laser to continuous wave mode, 10 watts of power, single pulse tissue exposure mode, for an on time of 0.1 seconds.

(5) Aim the helium neon beam at the cross mark.

(6) Return laser to proper storage location.

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D–13. Safety guidelines for handling of medical laser fiber delivery systems

a. Purpose: To promote safe and proper handling of laser fiber delivery systems and to limit the potential for fiber breakage, damage, and reduced efficiency during clinical laser procedure

b. Policy. Personnel handling laser fibers will assure compliance with all safety procedures and will consider the fiber an extension of the laser system, governed by applicable standards and regulations.

c. Procedures.

(1) Appropriate eye safety filters will be used with endo/microscopes.

(2) Laser room windows will be covered completely with appropriate filters if necessary.

(3) Fibers and associated equipment will be positioned to allow for safe traffic patterns in the room.

(4) The fiber will be examined for breaks or damage of the distal tip, the proximal connector, and the catheter sheath. Fiber will be calibrated according to manufacturer's directions. If deficiencies or damage are noted, another fiber must be obtained.

(5) Do not use clamps or other instruments to secure fiber in the operative site.

(6) Always use coaxial cooling that is appropriate to the procedure. **NEVER USE GAS TO PURGE A FIBER IN THE INTRAUTERINE CAVITY.**

(7) Never operate the laser unless you see the aiming beam (if used) and the tip of the fiber beyond the end of the endoscope.

(8) Monitor the fiber for distortion of the beam, decreased power transmission, and accumulation of debris on the tip.

(9) Never reuse a disposable fiber without manufacturer's directions.

(10) Always put the laser in standby mode when not aimed at a target.

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D–14. Safety guidelines for nonbeam hazards associated with medical lasers

a. Purpose. To recognize and effectively deal with a variety of potential nonbeam hazards that may be present during laser procedures.

b. Procedure.

(1) *Fire.*

(a) Never use alcohol in the operative field. Fibers may be rinsed in hydrogen peroxide or saline intraoperatively.

(b) Never place a hot fiber directly on paper drapes. Wait until tip is cool before contact is made with flammable material.

(c) Use fire-retardant drapes, damp packs, or pads. Fill pelvic cavity with saline or other appropriate solution during surgery.

(d) Put laser system in standby mode when procedure is interrupted or terminated.

(e) Avoid high levels of oxygen in the operative field.

(f) Avoid laser-beam exposure of the sheaths of flexible fiber endoscopes, since many of the sheaths are flammable.

(2) *Plume management.*

(a) Remove laser generated airborne contaminants from the energy impact site to reduce the transmission of potentially hazardous particulates.

(b) Position smoke evacuator in the operating room whenever plume is anticipated.

(c) Check operation of the plume management system prior to the beginning of the case.

(d) Check the plume filter monitor; if needed, install a clean filter.

(e) In-line filters with minimum 0.3 micrometer filtration will be placed between wall suction and the fluid canister for—

(1) Suction line not connected to evacuator.

(2) Cases producing minimal plume.

(3) Failure of evacuator before or during operation

(f) Distal collection port must not be more than 2 centimeters from impact site, when practical.

(g) All tubing, connectors, adaptors, and wands will be changed per case and disposed of according to biohazard procedures.

(3) *Electrical shock.*

(a) During service or maintenance, precautions must be taken against electrical shock, which may be fatal.

(b) Healthcare Laser System lasers shall be installed and operated in conformity with the National Electrical Code® (National Electrical Code is a registered trademark of the National Fire Protection Association, Inc., Quincy, MA.)

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D–15. Safety guidelines for carbon dioxide surgical laser operation

(Note: This guideline should be tailored for individual applications and unit requirements.)

a. General. The use of this surgical laser can be potentially hazardous to the operator, bystanders, or the patient if not properly used. The emergent beam can burn the skin or eyes and ignite clothing.

b. Procedures.

(1) Only authorized personnel, fully trained in the proper use of the laser, shall operate the laser.

(2) Remove the key from the key switch when the laser is not in use. Emergency use should be anticipated and made available.

(3) Direct the laser beam at the target board to assure the location and quality of the focal spot.

(4) All personnel within the operating theater shall wear eye protection during actual laser operations. The laser operator shall assure that eye protection is being worn prior to commencing laser operation.

(5) Use the focusing head having the shortest focal length applicable for each procedure. This will minimize any potential specular (mirror-like) reflections.

(6) Use wet towels that are kept wet to drape over the patient near the site of surgical incision.

(7) Use anesthetic gases with a minimum oxygen concentration to reduce combustibility. Do not use any cautery with this laser. Use anesthetic tubing that is flame resistant. Flash-fires fostered by oxygen have resulted in severe consequences.

(8) Wear flame-retardant surgical clothing. Check that laundering does not change flammability characteristics. Fabric softener is very bad in this respect.

(9) Do not direct the laser beam at flat unpainted metallic surfaces such as stainless steel.

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D–16. Safety guidelines for photocoagulators

(Note: This guideline should be tailored for individual applications and unit requirements.)

a. General. The use of the photocoagulator can be potentially hazardous to the operator, bystanders, or the patient if not properly used. The emergent beam can cause skin or eye injuries.

b. Procedures.

(1) Photocoagulators may be operated only by assigned physicians, following a presentation of the mechanics of treatment and operation of the equipment. Resident physicians will be instructed and observed by staff physicians. Staff physicians will be monitored by the Service Chief.

(2) Warning labels will be attached to each photocoagulator and a warning sign posted outside.

(3) Only medical personnel are permitted to observe photocoagulation procedures. Nonmedical personnel (such as, family or escorts) are to be instructed to wait in the patient waiting area until completion of the procedure unless suitable eye protection is provided to these individuals.

(4) All persons observing the treatment procedure will be instructed not to look directly at the photocoagulating light source or the high intensity reflections from the contact lens and other surfaces.

(5) Operators will become familiar with operating instructions accompanying each instrument. Instruments may not be left “ON” while the operator is not in attendance. Disable switches are to be operated to avoid inadvertent photocoagulation. Key-lock switches are to be left in the OFF position.

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APPENDIX E

MAXIMUM PERMISSIBLE EXPOSURES

E–1. Introduction

A complete listing of exposure limits for the MPEs of the eye and skin specified in AR 11–9 are provided in this appendix. These exposure limits are for MPE to laser radiation under conditions to which nearly all personnel may be exposed without adverse effects.

E–2. Scope

These values should be used as guides in the control of exposures and should not be regarded as fine lines between safe and dangerous levels. These values are based on the best available information from experimental studies. Tables E–1, E–2, and E–4 provide a complete list of laser exposure limits for both the eye and skin. Figures E–1 through E–11 provide graphs of exposure limits that may be difficult to calculate.

Table E–1
Maximum permissible exposure for small source ocular exposure to a laser beam

Wavelength (nm)	Exposure Duration, *t* (s)	MPE		Notes
		(J·cm^{-2})	(W·cm^{-2})	
Ultraviolet				
180 to 302	10^{-9} to 3×10^4	3×10^{-3}		Or 0.56 $t^{0.25}$ whichever is lower. (See tables E–5 and E–9 for limiting apertures.)
303	10^{-9} to 3×10^4	4×10^{-3}		
304	10^{-9} to 3×10^4	6×10^{-3}		
305	10^{-9} to 3×10^4	10×10^{-3}		
306	10^{-9} to 3×10^4	16×10^{-3}		
307	10^{-9} to 3×10^4	25×10^{-3}		
308	10^{-9} to 3×10^4	40×10^{-3}		
309	10^{-9} to 3×10^4	63×10^{-3}		
310	10^{-9} to 3×10^4	0.1		
311	10^{-9} to 3×10^4	0.16		
312	10^{-9} to 3×10^4	0.25		
313	10^{-9} to 3×10^4	0.40		
314	10^{-9} to 3×10^4	0.63		
315 to 400	10^{-9} to 10	$0.56\ t^{0.25}$		
315 to 400	10 to 3×10^4	1.0		
Visible and Near Infrared				
400 to 700	10^{-13} to 10^{-11}	1.5×10^{-8}		(See tables E–5 and E–6 for limiting apertures.) For multiple pulses apply correction factor C_p given in table E–3.
400 to 700	10^{-11} to 10^{-9}	$2.7\ t^{0.75}$		
400 to 700	10^{-9} to 18×10^{-6}	5.0×10^{-7}		
400 to 700	18×10^{-6} to 10	$1.8\ t^{0.75} \times 10^{-3}$		
400 to 450	10 to 100	1×10^{-2}		
450 to 500	10 to T_1		1×10^{-3}	
450 to 500	T_1 to 100	$C_B \times 10^{-2}$		
400 to 500	100 to 3×10^4		$C_B \times 10^{-4}$	
500 to 700	10 to 3×10^4		1×10^{-3}	
700 to 1050	10^{-13} to 10^{-11}	$1.5\ C_A \times 10^{-8}$		
700 to 1050	10^{-11} to 10^{-9}	$2.7\ C_A\ t^{0.75}$		
700 to 1050	10^{-9} to 18×10^{-6}	$5.0\ C_A \times 10^{-7}$		
700 to 1050	18×10^{-6} to 10	$1.8\ C_A\ t^{0.75} \times 10^{-3}$		
700 to 1050	10 to 3×10^4		$C_A \times 10^{-3}$	
1050 to 1400	10^{-13} to 10^{-11}	$1.5\ C_C \times 10^{-7}$		
1050 to 1400	10^{-11} to 10^{-9}	$27.0\ C_C\ t^{0.75}$		
1050 to 1400	10^{-9} to 50×10^{-6}	$5.0\ C_C \times 10^{-6}$		
1050 to 1400	50×10^{-6} to 10	$9.0\ C_C\ t^{0.75} \times 10^{-3}$		
1050 to 1400	10 to 3×10^4		$5.0\ C_C \times 10^{-3}$	

Table E–1
Maximum permissible exposure for small source ocular exposure to a laser beam (continued)

Wavelength (nm)	Exposure Duration, *t* (s)	MPE		Notes
		(J·cm^{-2})	(W·cm^{-2})	
Far Infrared				
1400 to 1500	10^{-9} to 10^{-3}	0.1		For multiple pulses apply correction factor C_p given in table E–3. (See tables E–5 and E–6 for limiting apertures.)
1400 to 1500	10^{-3} to 10	$0.56\ t^{0.25}$		
1400 to 1500	10 to 3×10^4		0.1	
1500 to 1800	10^{-9} to 10	1.0		
1500 to 1800	10 to 3×10^4		0.1	
1800 to 2600	10^{-9} to 10^{-3}	0.1		
1800 to 2600	10^{-3} to 10	$0.56\ t^{0.25}$		
1800 to 2600	10 to 3×10^4		0.1	
2600 to 10^6	10^{-9} to 10^{-7}	1×10^{-2}		
2600 to 10^6	10^{-7} to 10	$0.56\ t^{0.25}$		
2600 to 10^6	10 to 3×10^4		0.1	

Notes:
[1] For repeated (pulsed) exposures, see chapter 4.
[2] The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$ nm, (for example, 180 nm–302 nm means $180 \leq \lambda < 302$ nm).
[3] Table adapted from ANSI Z136.1-2000.
[4] The irradiance (W·cm^{-2}) values for the MPEs in table E–1 can be obtained by dividing the radiant exposure (J·cm^{-2}) 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.

Table E–2
Maximum permissible exposure for extended source ocular exposure to a laser beam for long-exposure durations†

Wavelength (nm)	Exposure Duration, t (s)	MPE ($J\ cm^{-2}$) except as noted	MPE ($W\ cm^{-2}$) except as noted	Notes
Visible				
400 to 700	10^{-13} to 10^{-11}	$1.5\ C_E \times 10^{-8}$		(See tables E–5 and E–6 for limiting apertures.)
400 to 700	10^{-11} to 10^{-9}	$2.7\ C_E\ t^{0.75}$		
400 to 700	10^{-9} to 18×10^{-6}	$5.0\ C_E \times 10^{-7}$		
400 to 700	18×10^{-6} to 0.7	$1.8\ C_E\ t^{0.75} \times 10^{-3}$		
Dual Limits for 400 nm–600 nm visible laser exposure. Choose lower MPE of Photochemical and Thermal†				
Photochemical				
For $\alpha \le 11$ mrad, the MPE is expressed as irradiance and radiant exposure[a]				
400 to 600	0.7 to 100	$C_B \times 10^{-2}$		
400 to 600	100 to 3×10^4		$C_B \times 10^{-4}$	
For $\alpha > 11$ mrad and $\alpha < \gamma$				
400 to 600	0.7 to $(\alpha/1.1\ \text{mrad})^2$	$(\gamma/11\ \text{mrad})^2 \times C_B \times 10^{-2}$		
400 to 600	$(\alpha/1.1\ \text{mrad})^2$ to 3×10^4		$C_B \times 10^{-4}$	
For $\alpha > \gamma$ and $\alpha < 110$ mrad				
400 to 600	0.7 to $(\alpha/1.1\ \text{mrad})^2$	$(\alpha/11\ \text{mrad})^2 \times C_B \times 10^{-2}$		(See tables E–5 and E–6 for limiting apertures.)
400 to 600	$(\alpha/1.1\ \text{mrad})^2$ to 3×10^4		$C_B \times 10^{-4}$	
For $\alpha > 110$ mrad				
400 to 600	0.7 to 1×10^4	$(\alpha/11\ \text{mrad})^2 \times C_B \times 10^{-2}$		(See table E–5 for limiting cone angle γ.).
400 to 600	1×10^4 to 3×10^4		$(\alpha/11\ \text{mrad})^2 \times C_B \times 10^{-4}$	
The MPE may also be expressed as radiance or integrated radiance averaged over γ*				
400 to 600	10 to 1×10^4	$100\ C_B\ J \cdot cm^{-2} \cdot sr^{-1}$		
400 to 600	1×10^4 to 3×10^4		$C_B \times 10^{-2}\ W \cdot cm^{-2} \cdot sr^{-1}$	
Thermal				
400 to 700	18×10^{-6} to T_2	$1.8\ C_E\ t^{0.75} \times 10^{-3}$		
400 to 700	T_2 to 3×10^4		$1.8\ C_E\ T_2^{-0.25} \times 10^{-3}$	

†Thermal hazard results in a lower MPE for exposure duration < 0.7 s

Table E–2
Maximum permissible exposure for extended source ocular exposure to a laser beam for long-exposure durations† (continued)

Wavelength (nm)	Exposure Duration, t (s)	MPE (J·cm^{-2}) except as noted	MPE (W·cm^{-2}) except as noted	Notes
Near Infrared				
700 to 1050	10^{-13} to 10^{-11}	1.5 C_A C_E × 10^{-8}		(See tables E−5 and E−6 for limiting apertures.)
700 to 1050	10^{-11} to 10^{-9}	2.7 C_A C_E $t^{0.75}$		
700 to 1050	10^{-9} to 18 × 10^{-6}	5.0 C_A C_E × 10^{-7}		
700 to 1050	18 × 10^{-6} to T_2	1.8 C_A C_E $t^{0.75}$ × 10^{-3}		
700 to 1050	T_2 to 3 × 10^4		1.8 C_A C_E $T_2^{-0.25}$ × 10	
1050 to 1400	10^{-13} to 10^{-11}	1.5 C_C C_E × 10^{-7}		
1050 to 1400	10^{-11} to 10^{-9}	27.0 C_C C_E $t^{0.75}$		
1050 to 1400	10^{-9} to 50 × 10^{-6}	5.0 C_C C_E × 10^{-6}		
1050 to 1400	50 × 10^{-6} to T_2	9.0 C_C C_E $t^{0.75}$ × 10^{-3}		
1050 to 1400	T_2 to 3 × 10^4		9.0 C_C C_E $T_2^{-0.25}$ × 10^{-3}	

Notes:
[1] The MPE expressed as an integrated radiance (L_p = 100 C_B J·cm^{-2}·sr^{-1}) and radiance (L_e = C_B × 10^{-2} W·cm^{-2}·sr^{-1}) is averaged over a limiting cone angle γ. For sources smaller than γ, these values may be expressed in terms of radiant exposure (J·cm^{-2} for 10 s ≤ t < 100 s) and as irradiance (W·cm^{-2} for t ≥ 100 s). See table E–5 for values of γ.
[2] For repeated (pulsed) exposures, see chapter 4.
[3] In the wavelength region (400 nm–600 nm), the MPE is the lower value of the photochemical MPE and the thermal MPE.
[4] The irradiance (W·cm^{-2}) values for the MPEs in table E–2 can be obtained by dividing the radiant exposure (J·cm^{-2}) 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.

Table E–3
Parameters and correction factors[1]

Parameters/Correction Factors	Wavelength[†2] (nm)
$T_1 = 10 \times 10^{0.02(\lambda - 450)}$ [3]	450 to 500
$T_2 = 10 \times 10^{(\alpha - 0.0015)/0.0985}$ [4]	400 to 1400
$C_B = 1.0$	400 to 450
$C_B = 10^{0.02(\lambda - 450)}$	450 to 600
$C_A = 1.0$	400 to 700
$C_A = 10^{0.002(\lambda - 700)}$	700 to 1050
$C_A = 5.0$	1050 to 1400
$C_P = n^{-0.25}$ [5]	180 to 10^6
$C_E = 1.0 \quad \alpha < \alpha_{min}$	400 to 1400
$C_E = \alpha/\alpha_{min} \qquad \alpha_{min} \le \alpha \le \alpha_{max}$	400 to 1400
$C_E = \alpha^2 / (\alpha_{max} \cdot \alpha_{min}) \qquad \alpha > \alpha_{max}$	400 to 1400
$C_C = 1.0$	1050 to 1150
$C_C = 10^{0.018(\lambda - 1150)}$	1150 to 1200
$C_C = 8$	1200 to 1400

Notes:
[1] See figures for graphic representation.
[2] † - the wavelength region λ_1 to λ_2 means $\lambda_1 \le \lambda < \lambda_2$ (for example., 550 nm–700 nm means $550 \le \lambda < 700$ nm).
[3] T_1 = 10 s for λ = 450 nm, and T_1 = 100 s for λ = 500 nm.
[4] T_2 = 10 s for α < 1.5 mrad, and T_2 = 100 s for α > 100 mrad.
[5] See section 4-5d for explanation of C_P and for explanation of PRFs below 55 kHz (400 nm–1050 nm) and below 20 kHz (1050 nm–1400 nm).
[6] For wavelengths between 400 nm and 1400 nm:
α_{min} = 1.5 mrad $\qquad \alpha_{max}$ = 100 mrad
[7] Wavelengths must be expressed in nanometers and angles in radians for calculations.

Table E–4
Maximum permissible exposure for skin exposure to a laser beam

Wavelength (nm)	Exposure Duration, t (s)	MPE (J cm^{-2}) except as noted	MPE (W cm^{-2}) except as noted	Notes
Ultraviolet				
180 to 302	10^{-9} to 3×10^4	3×10^{-3}		Or 0.56 $t^{0.25}$ whichever is lower. 3.5 mm limiting aperture: (See table E–5.)
303	10^{-9} to 3×10^4	4×10^{-3}		
304	10^{-9} to 3×10^4	6×10^{-3}		
305	10^{-9} to 3×10^4	1.0×10^{-2}		
306	10^{-9} to 3×10^4	1.6×10^{-2}		
307	10^{-9} to 3×10^4	25×10^{-3}		
308	10^{-9} to 3×10^4	40×10^{-3}		
309	10^{-9} to 3×10^4	63×10^{-3}		
310	10^{-9} to 3×10^4	0.1		
311	10^{-9} to 3×10^4	0.16		
312	10^{-9} to 3×10^4	0.25		
313	10^{-9} to 3×10^4	0.40		
314	10^{-9} to 3×10^4	0.63		
315 to 400	10^{-9} to 10	$0.56\ t^{0.25}$		
315 to 400	10 to 10^3	1.0		
315 to 400	10^3 to 3×10^4		1×10^{-3}	
Visible and Near Infrared				
400 to 1400	10^{-9} to 10^{-7}	$2\ C_A \times 10^{-2}$		3.5 mm limiting aperture: (See table E–5.)
400 to 1400	10^{-7} to 10	$1.1\ C_A\ t^{0.25}$		
400 to 1400	10 to 3×10^4		$0.2\ C_A$	
Far Infrared				
1400 to 1500	10^{-9} to 10^{-3}	0.1		(See table E–5 for limiting apertures.)
1400 to 1500	10^{-3} to 10	$0.56\ t^{0.25}$		
1400 to 1500	10 to 3×10^4		0.1	
1500 to 1800	10^{-9} to 10	1.0		
1500 to 1800	10 to 3×10^4		0.1	
1800 to 2600	10^{-9} to 10^{-3}	0.1		
1800 to 2600	10^{-3} to 10	$0.56\ t^{0.25}$		
1800 to 2600	10 to 3×10^4		0.1	
2600 to 10^6	10^{-9} to 10^{-7}	1×10^{-2}		
2600 to 10^6	10^{-7} to 10	$0.56\ t^{0.25}$		
2600 to 10^6	10 to 3×10^4		0.1	

Note:

[1] See table E–3 for correction factor C_A.

[2] The irradiance (W·cm^{-2}) values for the MPEs in table E–4 can be obtained by dividing the radiant exposure (J·cm^{-2}) 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.

Table E–5
Limiting apertures (irradiance and radiant exposure) and limiting cone angles γ (radiance and integrated radiance) for hazard evaluation and accessible emission limit determination

Spectral Region (nm)	Duration (s)	Aperture Diameter (mm) Eye	Skin
180 to 400	10^{-9} to 0.3 0.3 to 10 * 10 to 3 x 10^4	1.0 1.5 $t^{0.375}$ 3.5	3.5 3.5 3.5
400 to 1400	10^{-13} to 3 x 10^4	7.0	3.5
1400 to 10^5	10^{-9} to 0.3 0.3 to 10^a 10 to 3 x 10^4	1.0 1.5 $t^{0.375}$ 3.5	3.5 3.5 3.5
10^5 to 10^6	10^{-9} to 3 x 10^4	11.0	11.0
		Limiting Cone Angle, γ (mrad)	
400 to 600	0.7 s to 100 100 to 10^4 10^4 to 3 × 10^4	11 1.1 × $t^{0.5}$ 110	

Notes:
[1] Under normal conditions, these exposure duration would not be used for hazard evaluation.
[2] The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$ nm, (for example 315 nm–400 nm means $315 \leq \lambda < 400$ nm).

Table E–6
Measurement apertures for classification[1]

Spectral Region (nm)	Duration (s)	Aperture Diameter (mm)	Visible Optics Transmission
180-302	10^{-9} to 0.3	1.0	<2%
	0.3 to 10 [2]	$1.5\ t^{0.375}$	
	10 to 3×10^{4}	3.5	
302-400	10^{-9} to 0.3	7.0	70%
	0.3 to 10 [3]	$11\ t^{0.375}$	
	10 to 3×10^{4}	25.0	
400-700	10^{-9} to 3×10^{4}	50 [4]	90%
700-1400	10^{-9} to 3×10^{4}	50 [4]	70%
1400-2800	10^{-9} to 0.3	7.0	70%
	0.3 to 10 [3]	$11\ t^{0.375}$	
	10 to 3×10^{4}	25.0	
2800-10^{5}	10^{-9} to 0.3	1.0	<2%
	0.3 to 10 [3]	$1.5\ t^{0.375}$	
	10 to 3×10^{4}	3.5	
10^{5} to 10^{6}	10^{-9} to 3×10^{4}	11.0	<2%

Notes:
1 These apertures are used for the measurement of optical power or energy for the purpose of laser classification.
2 Under normal conditions, these exposure durations would not be used for classification.
3 When the laser output is intended to be viewed with optics (excluding ordinary eyeglasses) or the LSO determines that there is a reasonable probability of accidental viewing with optics, 7-power optics with a 50-mm entrance aperture and a 7-mm exit aperture is assumed if the following conditions are met:
(a) Viewing with optics presents a more severe hazard than unaided viewing.
(b) The viewing time is sufficient to constitute a hazard.
4 Otherwise, the limiting apertures for the eye from table E–5 apply. For the specific case of optical viewing with beam collecting instruments, the apertures listed in table 5 for hazard evaluation apply to the exit beam of the optical instrument.
5 The wavelength region $\lambda 1$ to $\lambda 2$ means $\lambda 1 \le \lambda < \lambda 2$, (for example, 315 nm–400 nm means $315 \le \lambda < 400$ nm).

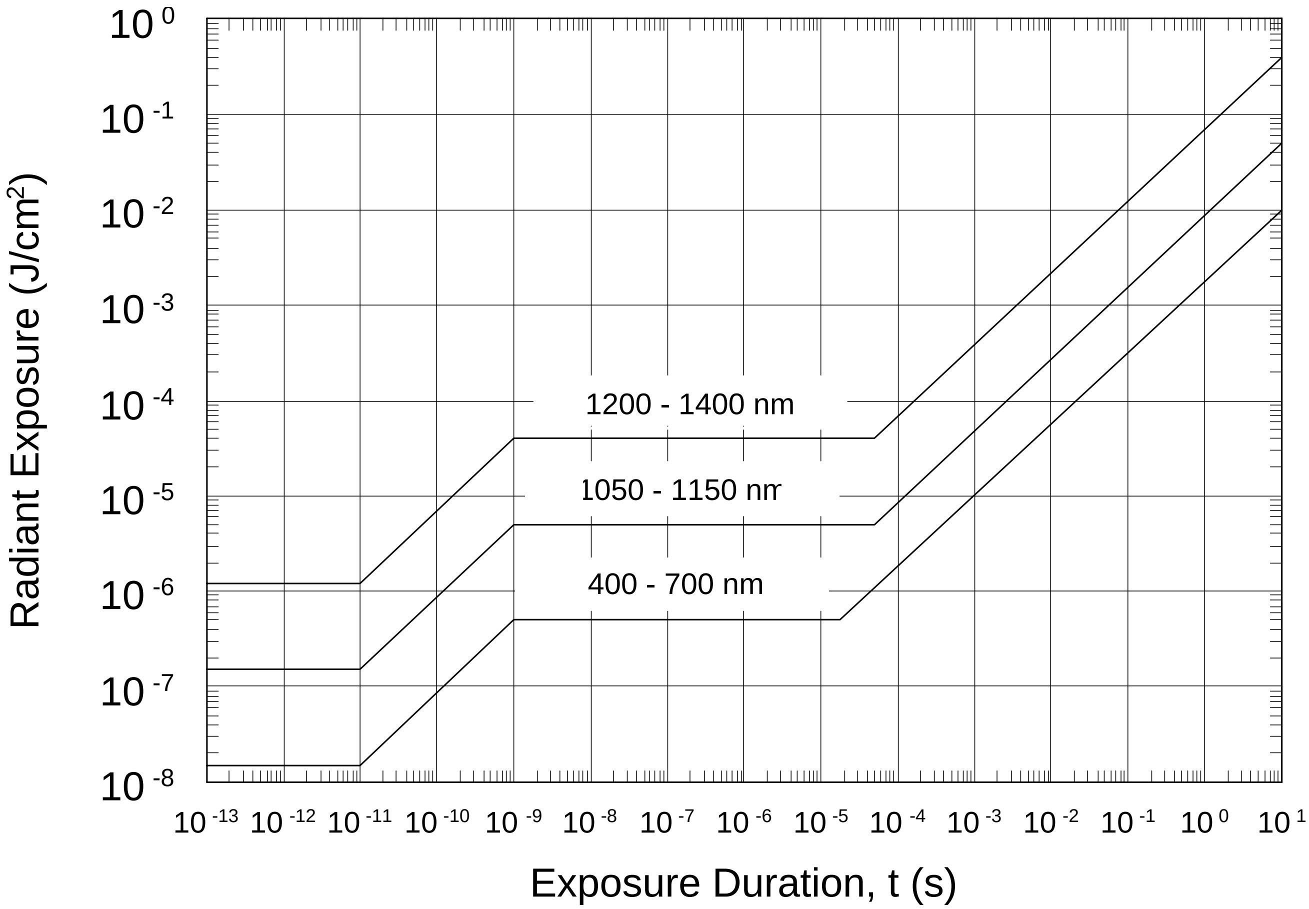

Figure E–1. Maximum permissible exposures for visible and near infrared (400 nanometers to 1400 nanometers) for pulsed small sources

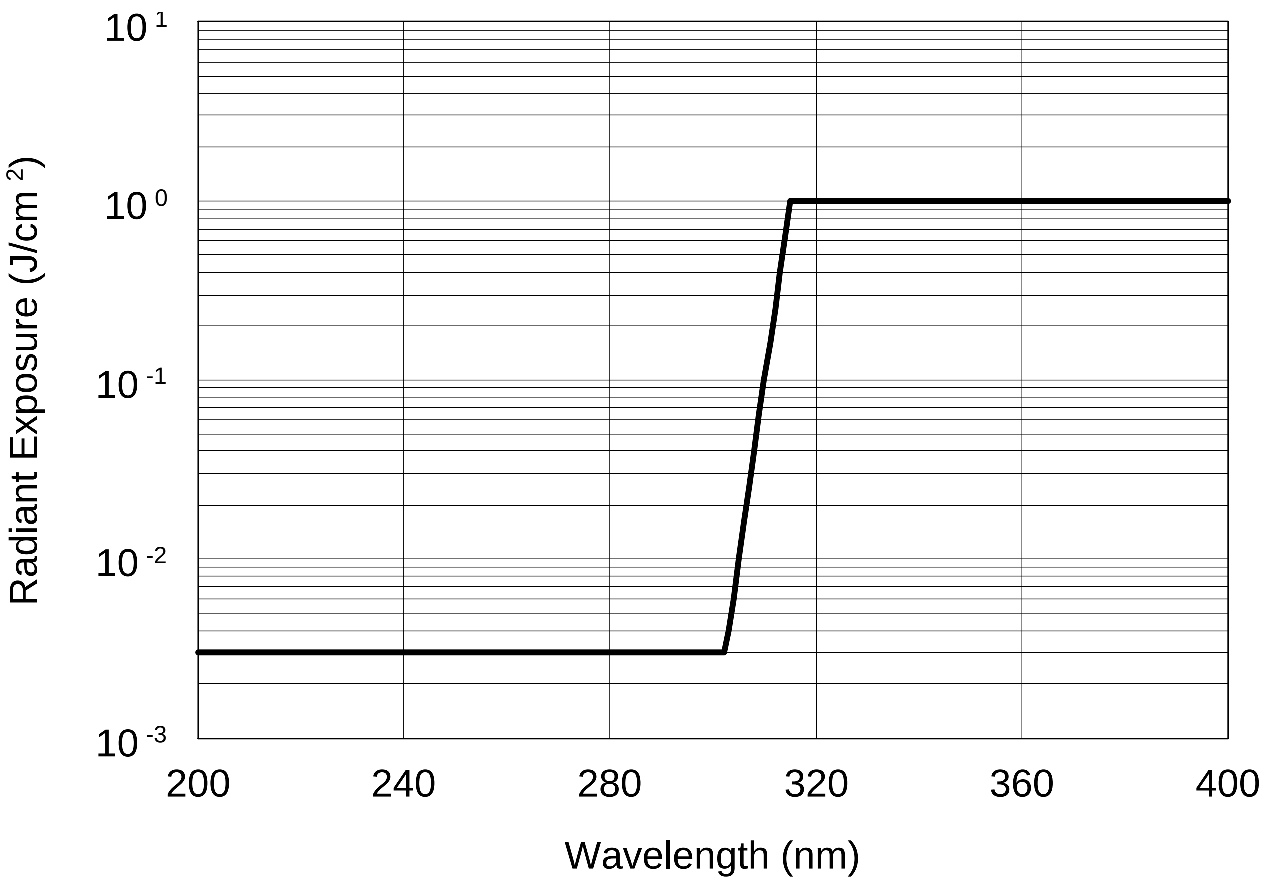

Figure E–2. Maximum permissible exposures for small and extended source ultraviolet radiation for exposure durations from 10^{-9} to 30,000 seconds for ocular exposures and 10^{-9} to 10^{3} seconds for skin exposure

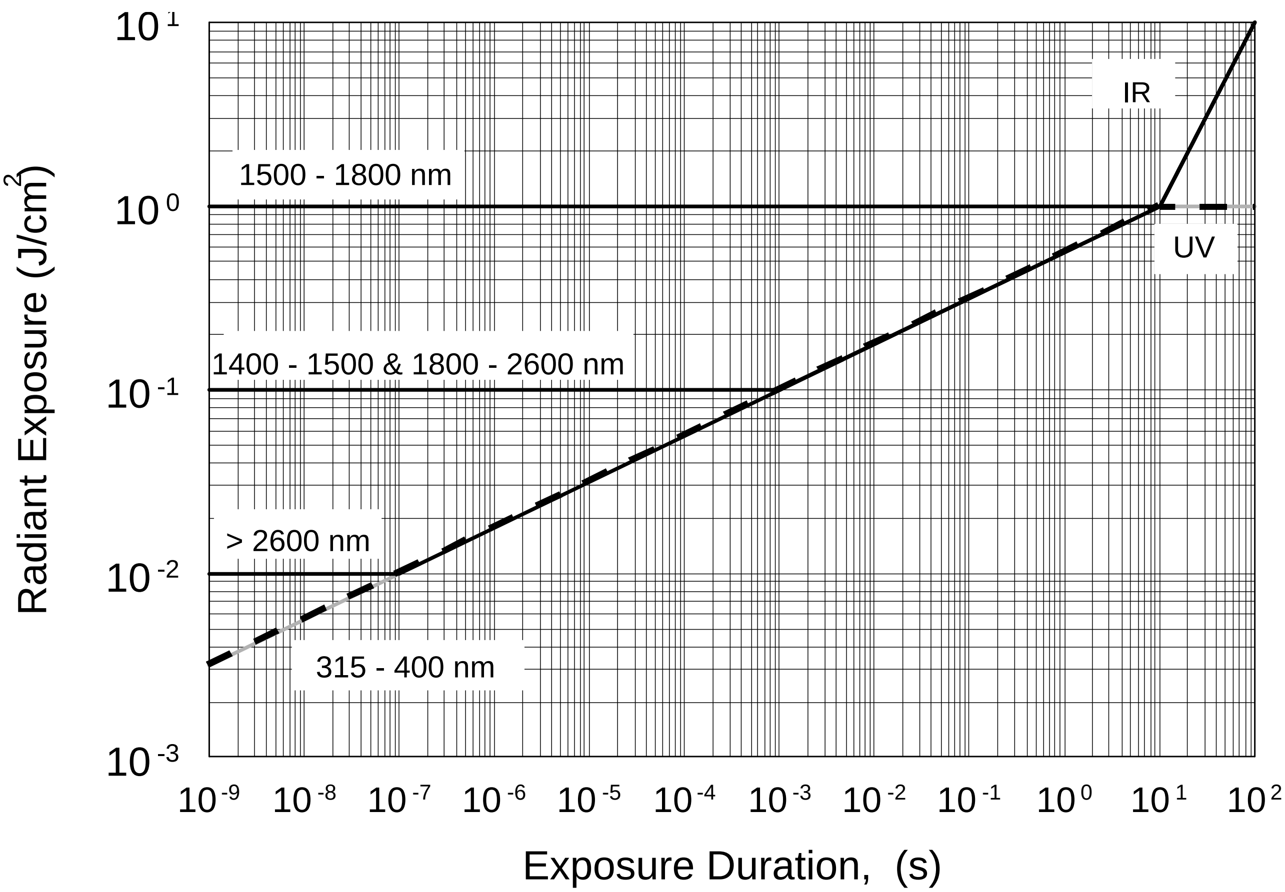

Figure E–3. Maximum permissible exposures for ultraviolet (315 nanometers to 400 nanometers) and infrared (1400 nanometers to 1 millimeter) for single pulses or continuous exposure to small or extended sources

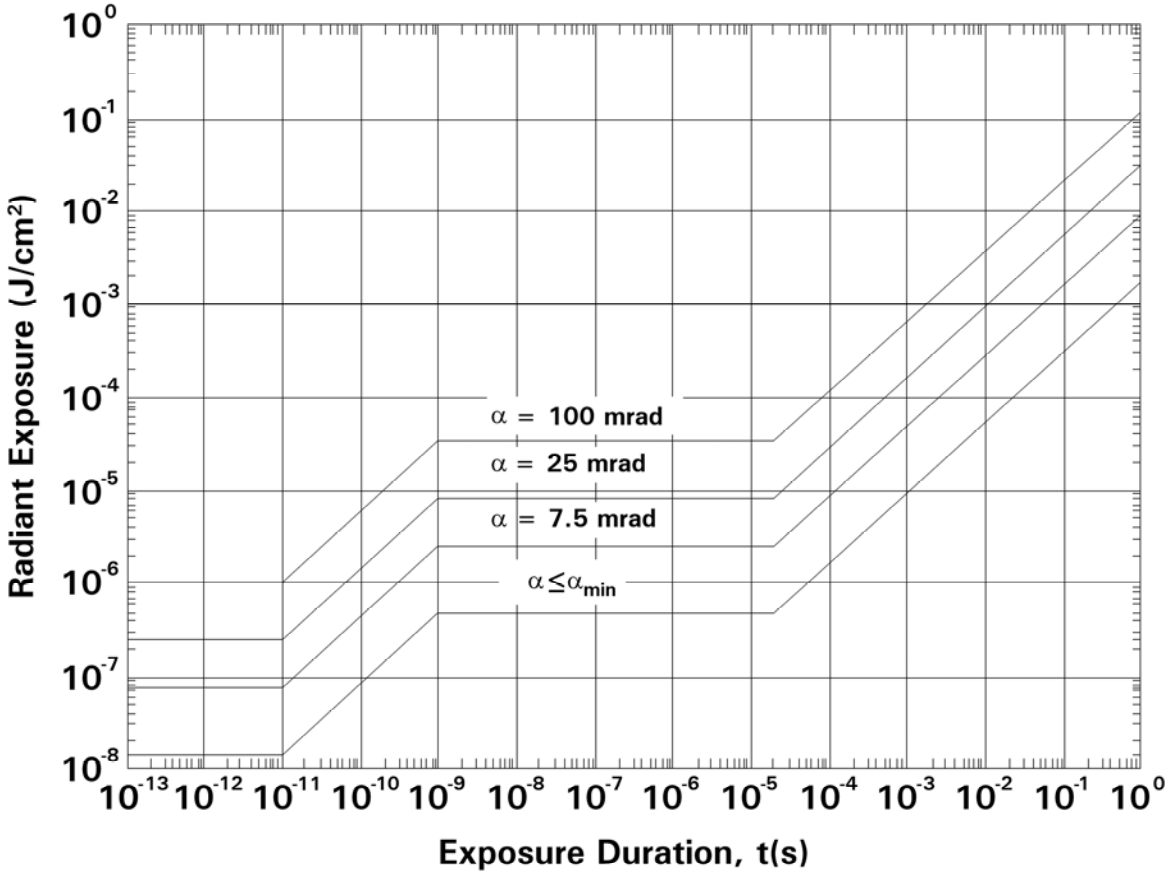

Figure E–4. Maximum permissible exposures for ocular exposure to visible laser radiation (400 nanometers to 700 nanometers) for single pulses or continuous exposure (small or extended sources)

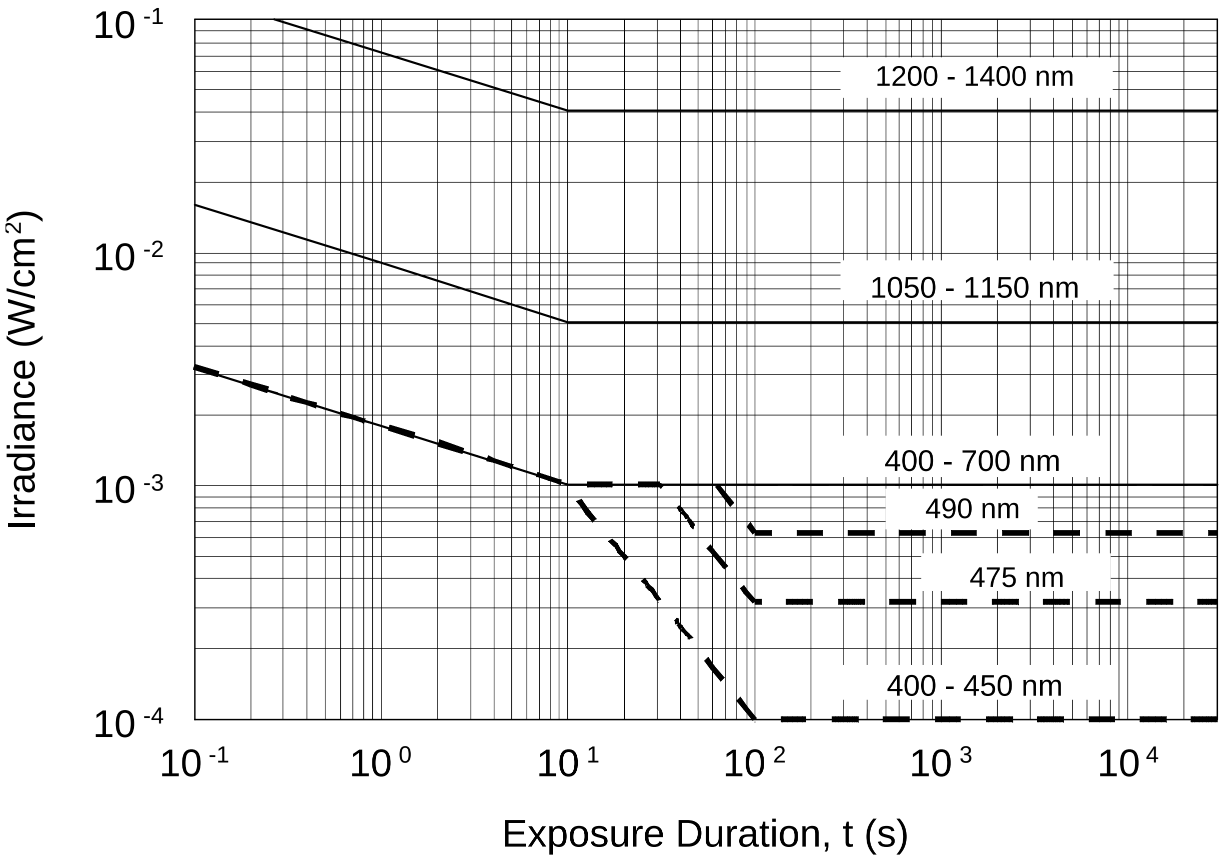

Figure E–5. Small source ocular maximum permissible exposures (α ≤1.5 milliradian) for visible and near infrared (400 nanometers to 1400 nanometers) (Solid lines are maximum permissible exposures based on thermal effects, and dashed lines are maximum permissible exposures based on photochemical effects)

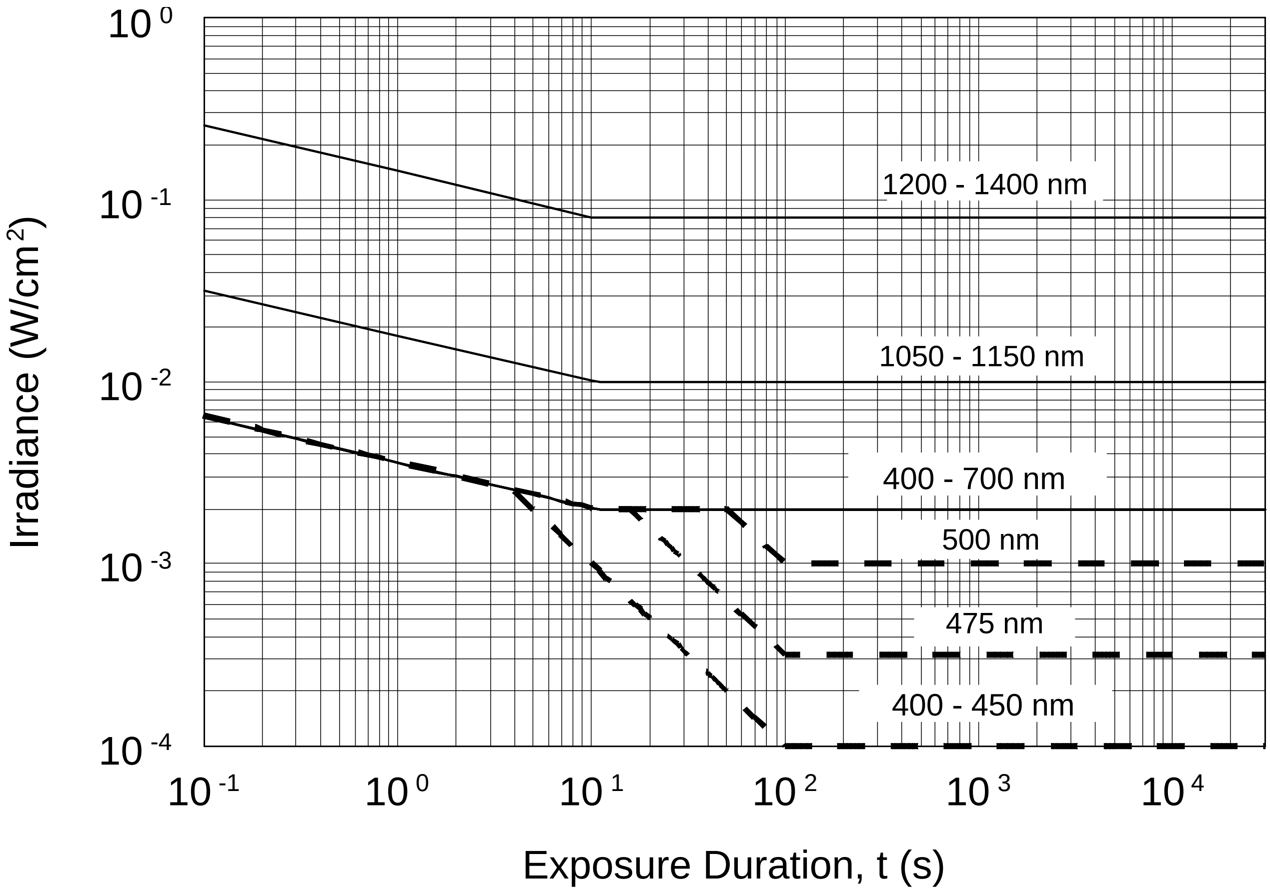

Figure E-6. Extended source ocular maximum permissible exposures (α = 3 milliradian) for visible and near infrared (400 nanometers to 1400 nanometers)
(Solid lines are maximum permissible exposures based on thermal effects, and dashed lines are maximum permissible exposures based on photochemical effects)

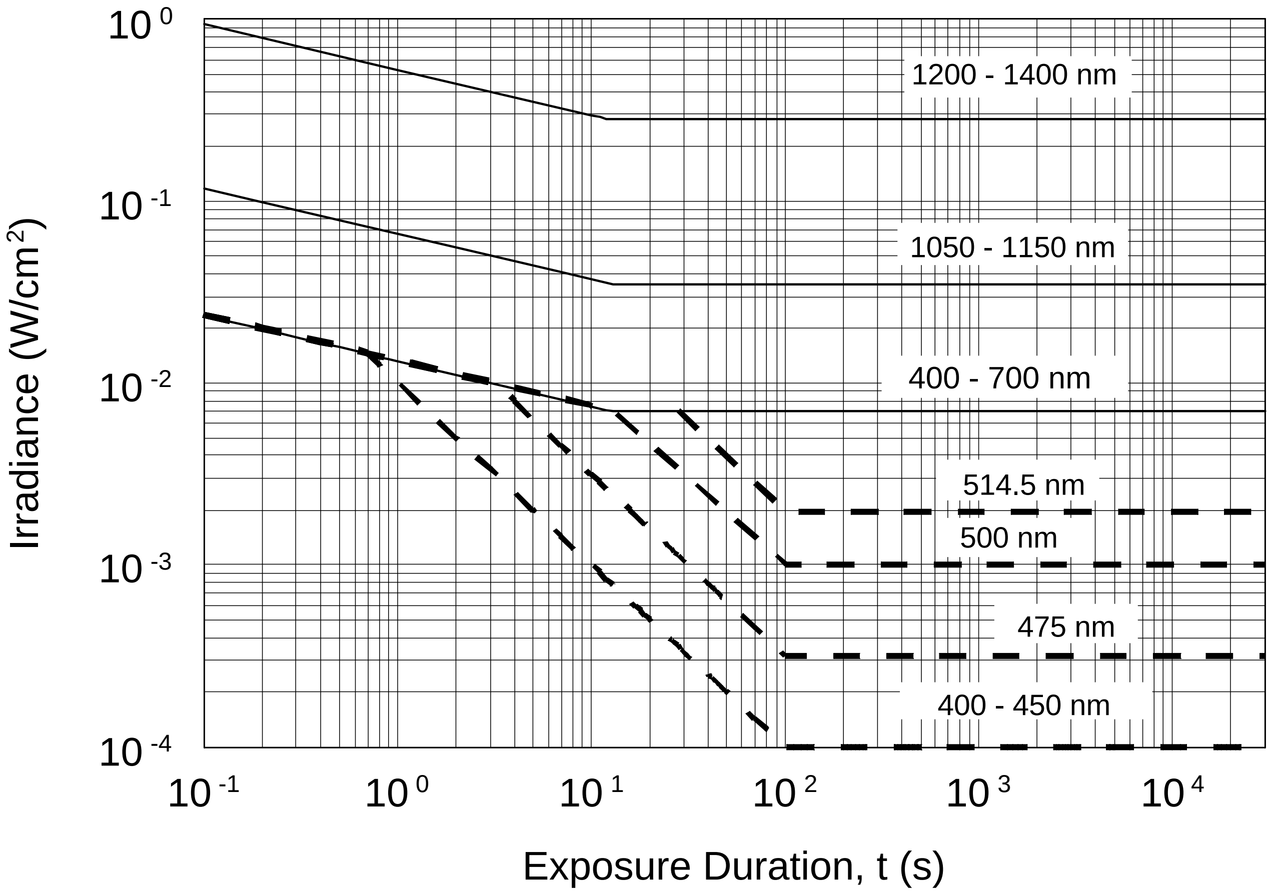

Figure E–7. Extended source ocular maximum permissible exposures (α = 11 milliradian) for visible and near infrared (400 nanometers to 1400 nanometers)
(Solid lines are maximum permissible exposures based on thermal effects, and dashed lines are maximum permissible exposures based on photochemical effects)

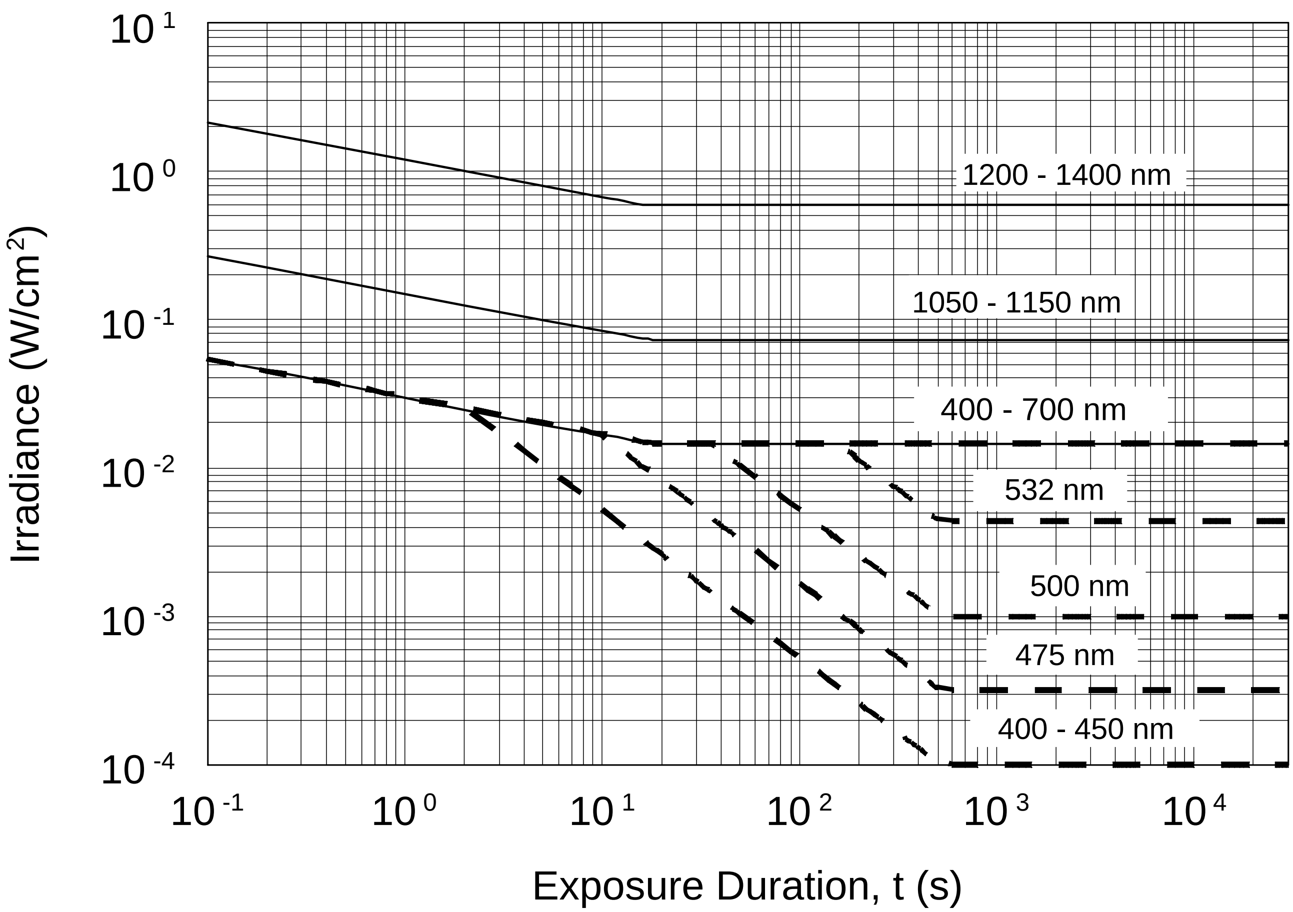

Figure E–8. Extended source ocular maximum permissible exposures (α = 25 milliradian) for visible and near infrared (400 nanometers to 1400 nanometers) (Solid lines are maximum permissible exposures based on thermal effects, and dashed lines are maximum permissible exposures based on photochemical effects)

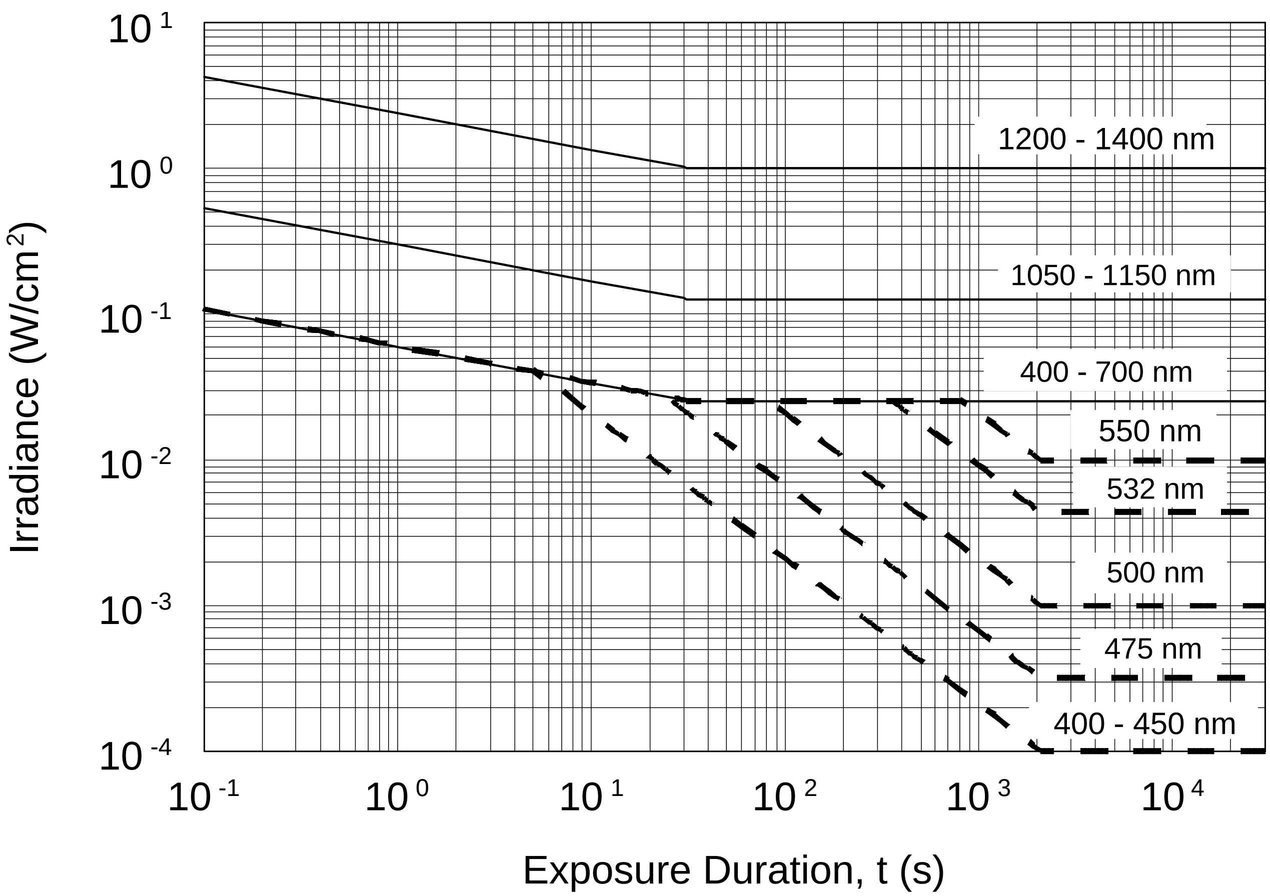

Figure E–9. Extended source ocular maximum permissible exposures (α = 50 milliradian) for visible and near infrared (400 nanometers to 1400 nanometers)
(Solid lines are maximum permissible exposures based on thermal effects, and dashed lines are maximum permissible exposures based on photochemical effects)

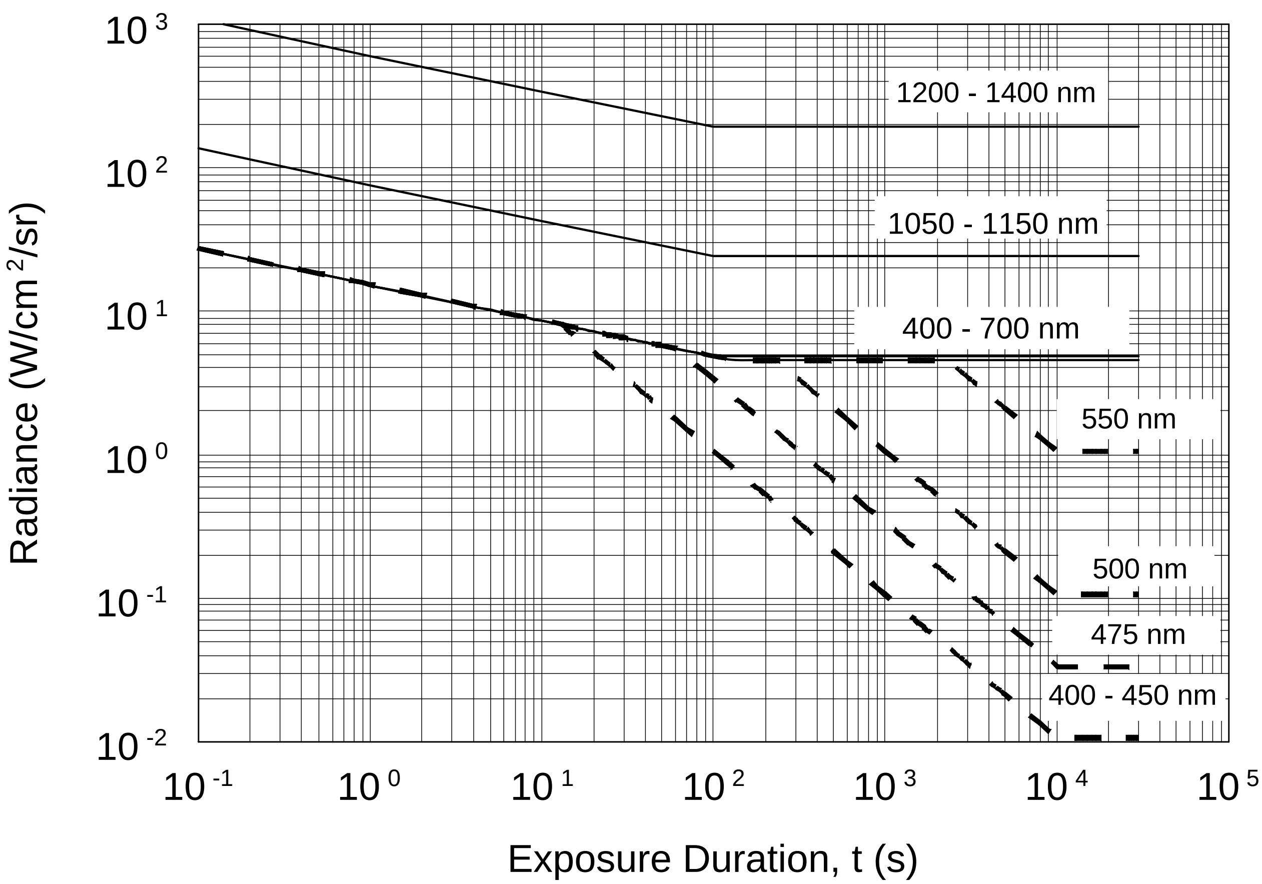

Figure E–10. Extended source ocular radiance maximum permissible exposures ($\alpha \geq 110$ milliradian) for visible and near infrared (400 nanometers to 1400 nanometers) (Solid lines are maximum permissible exposures based on thermal effects, and dashed lines are maximum permissible exposures based on photochemical effects)

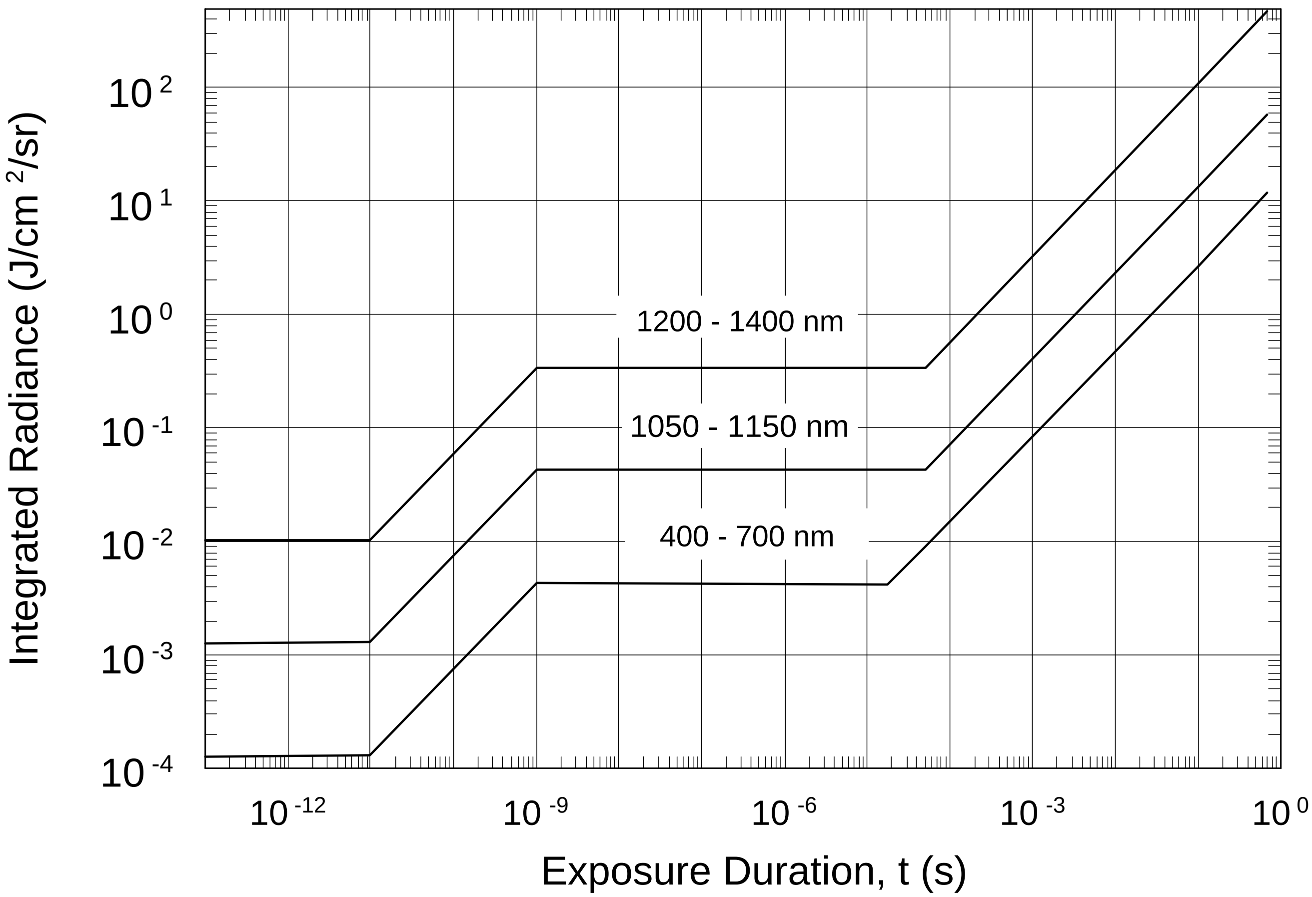

Figure E–11. Extended source ocular radiance maximum permissible exposures ($\alpha \geq$ 100 milliradian) for visible and near infrared (400 nanometers to 1400 nanometers) for pulsed or continuous wave exposures less than 1 second

APPENDIX F

CONTROL MEASURES

F–1. Introduction
This appendix contains control measures, administrative, procedural, and engineering 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.

F–2. Scope
The LSO/RSO or, when appropriate, the Range Control Officer have the authority to monitor and enforce the control of laser hazards. They can also provide guidance for protecting individuals from a laser systems hazard and the proper control measures to enforce during laser operations.

Table F–1
Administrative and procedural control measures for all laser classes

Administrative & Procedural Control Measures	Laser Classification						
	1	1M	2	2M	3a (3R)	3b (3B)	4
Laser Operator/Maintenance Manual	X[1]	X	X	X	X	X	X
Standard Operating Procedures	---[2]	---	---	---	---	X	X
Laser Output Limits	---	---	---	---	RSO Determination		
Education and Training	---	•[3]	•	•	•	X	X
Authorized Personnel	---	---	---	---	---	X	X
Beam Alignment Procedures	---	•	X	X	X	X	X
Spectators Not Permitted in Laser Controlled Area	---	---	---	---	---	•	X
Service Personnel	▼[4] MPE	▼ MPE	▼ MPE	▼ MPE	▼ MPE	X	X
Laser Optical Fiber Systems	MPE[5]	MPE	MPE	MPE	MPE	X	X
Laser Robotic Installations	---	---	---	---	---	X NHZ[6]	X NHZ
Eye Protection	---	*[7] MPE	---	* MPE	---	• MPE	X MPE
Protective Windows	---	---	---	---	---	X MPE	X NHZ
Protective Barriers and Curtains	---	---	---	---	---	•	•
Skin Protection	---	---	---	---	---	X MPE	X NHZ
Other Protective Equipment	Use may be required						
Warning Signs and Labels (Design Requirements)	•	•	•	•	•	X NHZ	X NHZ
Service and Repairs	RSO Determination						
Modifications and Laser Systems	RSO Determination						

Notes:

[1] X–Shall

[2] ---–No Requirement

[3] •–Should

[4] ▼–Shall, if enclosed Class 3b or Class 4

[5] MPE–Shall, if MPE is exceeded

[6] NHZ–nominal hazard zone analysis required

[7] *–Applicable only if optics are present

Table F–2
Engineering control measures for all laser classes

Engineering Control Measures	Laser Classification						
	1	1M	2	2M	3a (3R)	3b (3B)	4
Laser Protective Cover	X[1]	X	X	X	X	X	X
Without Laser Protective Cover	RSO Shall Establish Alternative Controls						
Interlocks on Protective Cover	▼[2]	▼	▼	▼	▼	X	X
Service Access Panel	▼	▼	▼	▼	▼	X	X
Key Control	---[3]	---	---	---	---	•[4]	X
Exit Port Cover (chapter 9–6e)	---	---	---	---	---	X	X
Remote Control Interlock Connector (chapter 9–6f)	---	---	---	---	---	X	X
Activation Warning System	---	---	---	---	X[†5]	X	X
Emission Indicator (chapter 9–6h)	---	---	---	---	X	X	X
Identification Label chapter (9–5a)	X	X	X	X	X	X	X
Hazard Warning Label (chapter 9–5k(1))	•[6]	•[6]	X	X	X	X	X
FDA Certification Label or Exemption Label	X	X	X	X	X	X	X
Laser Exit Port Label (chapter 9–k(2))	•[7]	•[6]	X	X	X	X	X
Interlock Label (chapter 9–5k(3))	X[8]	X[8]	X[8]	X[8]	X[8]	---	---
Laser Area (Range) Warning Signs (chapter 5–4)	---	•	---	•	•	X NHZ[9]	X NHZ
Optical Sights (chapter 9–5 i)	---	MPE[10]	MPE	MPE	MPE	MPE	MPE
Optical Ports (chapter 9–5 h)	---	MPE	MPE	MPE	MPE	MPE	MPE
Weight-on-Wheels Interlock (Airborne Systems Only) (chapter 9–6 j)	---	---	---	---	---	X	X
Open Beam Path	---	---	---	---	---	X NHZ	X NHZ
Indoor Laser Controlled Area (chapter 5–3)	---	MPE	---	---	•	X NHZ	X NHZ
Laser Outdoor Range Controls (chapter 6)	---	MPE	•	•	•	X NHZ	X NHZ

Notes:
1 X–Shall
2 ▼–Shall if enclosed Class 3b or Class 4
3 ---–No requirement
4 •–Should
5 †–If laser can emit more than 25 times the Class 1 AEL
6 Label to simply identify laser as Class 1 or Class 1 M
7 Lasers operating at invisible wavelengths only
8 Defeated interlock allows access to Class 3B or Class 4 emission levels
9 NHZ–nominal hazard zone analysis required
10 MPE–Shall, if MPE is exceeded

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APPENDIX G

EYE PROTECTION

G–1. Control measures

Control measures are aimed at limiting the laser exposure, thereby, reducing the risk of injury. Laser eye protective devices should only be used when engineering and administrative controls do not adequately control the hazard. Eye protection is often a necessary control measure.

G–2. Optical density requirements for laser systems

This appendix provides information on OD requirements for different laser systems. Table G–1 provides information on selecting eye protection. Technical information on commercially available laser protective devices is available from USACHPPM LORP website at: http://chppm-www.apgea.army.mil/laser/links/links.html.

Table G–1
Simplified method for selecting laser eye protection for small source viewing (wavelengths between 400 nanometers and 1400 nanometers)

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

Note: See table H–1 for a listing of currently fielded laser systems and the OD required to provide adequate protection for their safe use.

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APPENDIX H

SPECIFIC LASER SYSTEMS

H–1. Introduction
This appendix provides descriptions and safety information for currently fielded laser fire control systems. Fire control laser systems are laser rangefinders and laser designators, which in most cases are eye hazards that require eye protection for downrange viewing of the direct beam.

H–2. Fielded laser systems
The laser systems identified in this document have been evaluated and approved by the DOD Laser System Safety Review Board.

a. Description. The following is a listing of fielded laser systems as identified in FM 8–50 and MIL–STD–828A:

(1) *AC–130U, Laser Target Designator/Rangefinder (LTD/RF*). This is mounted on the AC–130U aircraft.

(2) *AH–1W, Night Targeting System.* This is a modification to the Marine Corps AH-1 Telescopic Sight Unit to include night targeting capability through the direct view optics using a Forward Looking Infrared (FLIR) and LD/LRF system with camera and video tracker.

(3) *Advanced Infrared Module–1 (AIM–1).* A Class 3b infrared diode, aiming laser (830 nm–850 nm wavelength) for use with NVGs. The AIM/Mini Laser Range (MLR) is mounted on Marine Corps XM-218, 50 caliber, M–60 and Aircraft Gun Unit–17B machine gun mounts. The AIM/EXL version is hard mounted on the AH–1 turret. AIM–1/D, AIM–1/DLR, AIM–1/MLR, AIM–1/EXL devices are integrated into the Army AH–1F helicopter or used separately or mounted on army rifles. ANVIS NVGs provide adequate protection against these lasers. CAT'S EYES NVGs do not protect against laser radiation.

(4) *AGES/AD, Laser Air to Air Gunnery Systems (LATAGS), and Precision Gunnery Training System (PGTS) for TOW and Dragon missiles.* These systems are an extension of and are similar to the MILES. The AGES/AD, LATAGS and PGTS systems emit infrared laser beams to simulate various air defense, airborne, and ground weapons systems to improve realism during training. The AN/GVT–1 is a simulator of a target illuminated by a laser; it consists of an infrared laser emitter covered by a diffuser. Table H–2 lists cautionary viewing distance for an eye exposed from within the infrared laser beam for various versions of the AGES/AD, LATAGS and PGTS, and AN/GVT–1 simulators. Since these systems are pointed toward the sky, aimed at a retroreflector mounted on a target in a restricted area, or contained within a diffuser, no optical radiation hazard exists during normal field exercises. Other potential hazards such as posed by the blast simulators must be considered.

(5) *AN/AAQ–14, Low-Altitude Navigation and Targeting Infrared for Night (LANTIRN).* LANTIRN is a two-pod system containing a terrain following radar, FLIR, LD, and in newer models, a target recognition system. Originally it was designed for the H–15E and H–16, and the targeting pod is now integrated with some U.S. Navy F–14s.

(6) *AN/AAQ–22, Navigational Thermal Imaging System.* Turret mounted FLIR/LRF on the Utility Helicopter (UH)–1N helicopter.

(7) *AN/AAS–33A, Target Recognition Attack Multi-sensor Laser System.* This system is mounted on the A6–E Aircraft and has a LD and FLIR.

(8) *AN/AAS–37.* LRF/LD mounted on the Marine Corps OV-10 Observation Aircraft.

(9) *AN/AAS–38A, Nite Hawk.* Pod mounted on lower left side of F/A–18 aircraft contains a FLIR and LD/LRF.

(10) *AN/ALQ–212, Advanced Tactical Infrared Countermeasures System*. Laser countermeasure system employed in several Army helicopter systems.

(11) *AN/GAQ–T1, Laser Designator Simulator System.*

(12) *AN/GVS–5, Handheld Laser Rangefinder*. Infrared Observation Set.

(13) *AN/PAQ–1, LTD.* This is a lightweight, hand-held, battery-operated laser device. Forward observers use the LD to designate targets.

(14) *AN/PAQ–3, Modular Universal Laser Equipment (MULE).* This is a Marine Corps laser designator used with laser energy homing munitions. The MULE is man portable, handheld, or tripod mounted and is used only in a dismounted mode.

(15) *AN/PAQ–4, AN/PAQ–4A, Pulsed AN/PAQ–4B and AN/PAQ–4C, Infrared Aiming Light.* These are Class 1 military exempt laser systems using an 830 nm wavelength laser diode.

(16) *AN/PED–1, Lightweight Laser Designator Rangefinder.* Modular, man-portable target observation and location determining system that has data/image export and laser designation capability.

(17) *AN/PEQ–1, Special Operating Forces Laser Target Marker (SOFLAM).* A man-portable LD used to mark targets for laser-guided ordnance and a laser rangefinder for determining the distance to a target.

(18) *AN/PEQ–2A, Infrared Target Pointer and Illuminator and Aiming Laser (ITPIAL).* A battery-operated, diode laser for small arms.

(19) *AN/PVS–6, Mini-Eyesafe Laser Infrared Observation Set (MELIOS).* Developed for infantry forward observers to measure distance. MELIOS is a Class 3a laser.

(20) *AN/TVQ–2, G/VLLD*. The G/VLLD is the principal ranging and laser-designating device used by Army artillery forward observers with laser energy homing munitions. The G/VLLD is capable of designating stationary or moving vehicular targets and may be used in a stationary, vehicle mounted, or tripod supported dismounted mode. The primary vehicle mount is the Fire Support Team Vehicle.

(21) *AN/VVG–1*. Ruby LRF mounted on the M55lAl Sheridan Vehicles.

(22) *AN/VVG–2*. Ruby LRF mounted on the M60A3 tank. It may be used with two filters, the green Eye-Safe Simulated Laser Rangefinder (ESSLR) filter and the red ESSLR filter. The green ESSLR is eye safe; the red ESSLR is less hazardous than the system without filters but not eye safe.

(23) *AN/VVG–3*. Nd:YAG LRF on the M1 tank and Light Armored Vehicle (LAV)– 105. An eye safe filter is available.

(24) *AN/VVS–1*. Ruby LRF mounted on the M60A2 tank.

(25) *Avenger*. Avenger air defense system, turret mounted LRF on a HMMWV.

(26) *Compact Laser Designator (CLD).* A small, lightweight LD and/or LRF used by the Navy.

(27) *Fire Arms Training Systems (FATS).* The FATS Engagement Skills Trainers are a group of weapons simulators produced by several corporations having multiple weapons configurations to simulate a variety of weapons and conditions.

(28) *Fire Support Sensor System (FS3).* The FS3 is an integration of Long Range Advanced Scout Sensor System and the Laser Designator Module (LDM) from the Lightweight Laser Designator Rangefinder (LLDR). The FS3 provides long range target acquisition, rangefinding, and designation capabilities to armor and infantry fire support teams.

(29) *GCP–1.* A COTS, small, lightweight, infrared aiming laser for use with night vision devices in target identification and night illumination. GCP−1 operates at a power of 30 mW with zoom beam from 30 degrees to 0.03 degrees (approximately 500 mrad–0.5 mrad). A built-in sensor prevents operation in daylight; however, it does not sufficiently reduce power in dark conditions to prevent hazardous illumination of unprotected personnel within the NOHD. The GCP−1A operates at 50 mW and does not incorporate the sensor.

(30) *Gun Laying and Positioning System (GLPS).* A Class 1 laser system, the GLPS is a tripod mounted gyroscope compass, electronic digital optical the odolite with an integrated laser rangefinder.

(31) *Havis Shield M16 Aiming Laser Light Assembly*. Designed to be used in conjunction with NVGs on DOD-controlled land.

(32) *High-Energy Laser Ordnance Negation System (HLONS)*. High-energy laser used to remotely destroy unexploded ordnance.

(33) *Indoor Simulated Marksmanship Trainer (ISMT) and Infantry Squad Trainer (IST).* Devices use Class 1 lasers (780 nm) in modified weapons to trace the aim point and calculate the location of simulated shots hitting a display screen. These lasers are commercially sold and registered with the FDA.

(34) *Infrared Zoom Laser Illuminator/Designator IZLID™.* A small, handheld device for use at night. (IZLID is a trademark of B. E. Myers & Co., Inc., Redmond, Washington).

(35) *Javelin Field Tactical Trainer* (*FTT).* A man-portable training system for the shoulder fired Javelin antitank tactical weapon system. The FTT is similar in appearance to the actual Javelin without the explosive parts. The FTT is a key-controlled trainer used during force-on-force training, gunner range qualification, and verification of operating skills in developing Javelin gunners. The FTT consists of the simulated round (SR) and an instructor station that monitors and records the functions of the SR. The SR includes a laser for simulation of target hits with a MILES compatible laser/detector system for scoring hits.

(36) *Laser Augmented Airborne TOW (LAAT) mounted in the AH–1F COBRA Helicopter:* The LAAT system consists of an LRF and receiver that is incorporated into the M65 TOW telescopic sight unit.

(37) *Light-Armored Vehicle* (*LAV)–105*: LAV–105 mm gun LRF.

(38) *LAV–Air Defense.* A turret-mounted carbon dioxide LRF.

(39) *Long Range Laser Pointer and Illuminator* (*LPL)–30*: A COTS Class 3b long range, infrared diode, aiming laser pointer and illuminator used by command to mark targets of choice to attacking forces equipped with the NVGs.

(40) *LRAS3.* The LRAS3 is a long range reconnaissance and surveillance system in both man-portable and vehicle-mounted configurations. The host vehicle is the HMMWV.

(41) *M55:* Helium–neon laser yank gunnery trainer.

(42) *Mobile Automated Instrumentation Suite*. Comprised of a mobile Command, Control, and Communications Center and five categories of player units and capable of supporting combined arms testing or training in real-time. The instrumentation suite is capable of data collection, test/exercise control, and combat simulation during Force-on-Force engagements.

(43) *Mast-Mounted Sight (MMS) on the OH–58D Scout Helicopter*: It incorporates thermal and optical sensors and a LRF/LD. It does not have direct-view daylight optics.

(44) *Mini-Laser Rangefinder (MLRF).* A lightweight, hand-held Nd:YAG LRF. The Radio Corporation of America MLRF has off-axis radiation that requires the use of large buffer zones. It is given the designation of AN/PVS–X to distinguish it from future MLRFs.

(45) *MILES:* Uses Class 1 and Class 3a lasers. The MILES is an ingenious system for scoring tactical exercises, dating from the early 1980s. This is accomplished through an infrared beam emitted from each weapon and detected by a target that can be a man or vehicle. These systems do not present a hazard during normal field exercises. However, the beam is quite concentrated upon leaving the transmitter and cautionary measures are advised at extremely close engagement ranges. Currently, MILES transmitters exist and are used from the original MILES, the MILES II, and the MILES 2000. MILES transmitters used for the M16 before 1986 were Class 3a devices as are the MILES 2000 M16 laser transmitters. In 1986, the original MILES (SAT was redesigned to be a Class 1 device. A person would be more likely to receive an eye injury from the impact of the blank fired at close range than from the infrared energy from the SAT. The MILES II, M16 rifle simulator is also a Class 1 device, but the other MILES II machine gun simulators are Class 3a.

(46) *Navy Mast-Mounted Sight (NMMS).* The NMMS is mounted above deck for television and IR imaging and incorporates a Class 1 LRF used to give range data for high-priority targets such as mines, ships, and small watercraft.

(47) *Nite Eagle: FLIR/LD/LRF.* Turret adapted from the Aquilla system for the U.S. Marine Corps UH–1N helicopters. In training and field-testing, laser firing is prohibited when the laser in flight is less than 1000 m from the target. This is required to prevent loss of track and possibility of the beam wandering off the target during slew and reorientation of the laser as the system passes over the target.

(48) *Nite Eye: Illuminator for IR Camera*. Approved only for use with output power below 30 mW.

(49) *Pave Penny (AN/AAS–35).* Laser tracker used on the A–10 and A–7 aircraft. It does not contain a laser.

(50) *Pave Spectre (AN/AVQ–19).* Laser tracker and LD used on C-130 gun ships.

(51) *Pave Spike (AN/AVQ-12).* A TV video tracker/laser target designator pod, used on F–4 and F–111 aircraft. It was normally loaded on the left forward AIM–7 missile station, thus, saving a wing station for munitions. It wasn't much bigger than the missile it excluded.

(52) *Pave Tack (AN/AVQ–26).* Advanced optronics, pod containing, stabilized turret with FLIR, LD and tracker used on the F–4, RF–4, and F–111F aircraft.

(53) *Schwartz Electro-Optic Controller Gun*. The controller gun is used with the Tank Weapon Gunnery Simulation System/Precision Gunnery System (TWGSS/PGS) transmitter. The controller gun can simulate the kill codes of various MILES weapon simulators and reactivate troops or weapons systems during training exercises. This is a Class 1 device and does not present a laser hazard.

(54) *Shillelagh Conduct of Fire Trainer* (*SCOFT).* IR laser simulator for training on the Shillelagh-Guided Missile System.

(55) *Target Acquisition and Designation System with Pilot Night Vision Sight* (*TADS/PNVS).* Mounted in the Apache Advanced Attack Helicopter.

(56) *Target Designator* (*TD)–100*: A day/night-aiming laser. For daytime use this device uses a Class 2 helium neon visible laser and for nighttime the TD–100 uses a Class 3b infrared laser diode.

(57) *Target Location and Observation System (TLOS).* The TLOS allows the individual soldier to find threat optical and electro-optical surveillance devices located on tanks, scouts, snipers, etc. Location of these devices will enhance the effectiveness for U.S. forces. TLOS also has capability to provide covert illumination for fire direction, improved night vision sighting and landing-zone marking. TLOS will also include range finding, precise target location, and digital battlefield capability.

(58) *TWGSS/PGS.* The TWGSS/PGS, with modified telescope, has a MILES type transmitter (SAAB version). The TADs, (MMS simulators, and the Hellfire Ground Support Simulator (all of which use a 1540-nm erbium laser and 904-nm laser diode) comprise the AGES II simulator system. AGES II is used on the KIOWA 50-caliber gun and rocket simulators and on the wirestrike modification to the APACHE, which includes a 20 mm area weapon system simulator.

b. Eye protection requirements. Tables H–1 through H–6 are a summary of the eye protection OD requirements for both unaided and optically aided viewing of the direct laser beam. The ODs given must be at the laser wavelength; otherwise, the eye protection will offer the user little or no protection at the laser wavelength. Table H–7 provides information concerning cautionary eye exposure distances to simulators and training devices.

Table H–1
Nominal ocular hazard distance (atmospheric attenuated), range safety information, and eye protection requirements for vehicle-mounted laser systems

Device/Mounting		NOHD		NOHD–M			Buffer Zone (Buffer Angle) each side		Safety Filters	Required Eye Protection		
	wave-length	multi-pulse	single pulse	7x50 binoc	8-cm optics	12-cm optics	static	moving	built-in[1] or clip-on OD	unaided OD	aided OD	single pulse OD
	nm	kilometers		kilometers			milliradians					
AN/VVG–1 (M551A1)[2]	694.3		9	32	47	67	2	not allowed	Clip-on 5	5.8	5.8	
AN/VVS–1 (M60A2)[2]	694.3		9	32	36	44	5	10	Clip-on 5	5.8	5.8	
AN/VVG–2 (M60A3)[2]	694.3		8	30	40	47	2	5	Clip-on 5	5.8	5.8	
red ESSLR	694.3		0.3	1.8			2	5				
green ESSLR	694.3		0	0	0	0	N/A	5				
AN/VVG–3 (M1)			7	25	35	44	2	5	5	4.7	4.7	
AN/VVG–3 (LAV-105)			8.2	32	41	50	2	5	5	4.7	4.7	
ESSLR			0	0	0	0	N/A	N/A				
AVENGER (HMMWV)		0	0	0	0	0	N/A	N/A		0	0	
AD LRF (LAV)	10600	0	0	0	0	0	N/A	N/A		4.0	4.7	
FS3 Rangefinder Designator	1540 1064	0 25	0 16	0 64/48						0 5.5	0 5.5	0 5.5
HLONS	1060	22	22	153	---	---	2	N/A	Built-in 5	5.3	5.3	

Notes:
[1] Assume the built-in safety filter only protects against the wavelength of the laser in which it is installed and that it does not always protect against other laser wavelengths.
[2] Target must be 10 m away from the tank to avoid diffuse reflection hazard.

Table H–2
Nominal ocular hazard distance (atmospheric attenuated), range safety information, and eye protection requirements for man-transportable laser systems

Device/Mounting		NOHD		NOHD–M			Buffer Zone (Buffer Angle) each side		Safety Filters	Required Eye Protection		
	wave-length	multi-pulse	single pulse	7x50 binoc	8-cm optics	12-cm optics	static	moving	built-in[1] or clip-on OD	unaided OD	aided OD	single pulse OD
	nm	kilometers		kilometers			milliradians					
AN/GAQ–T1 (LD82LB) LDSS)	1064	12.5	-	38	43	52	5	N/A	Yes	4.6	5.5	
AN/GVS–5 (Handheld)	1064		2.7	13	21	27	10	N/A	5	3.7	4.4	
red filter (19 dB[2])	1064		0.29	1.8	1.8	-	10	N/A				
yellow filter (29dB)	1064		0.056	0.55	0.55	-	10	N/A				
AN/PAQ–1	1064	7	3.5	15	33	43	10	N/A	4	4.2	5.8	
AN/PAQ–3 (MULE) (Tripod)	1064								5	3.9	5.6	
Designator–day		20	12	53	64	78	2	N/A				
Designator–night		20	12	53	64	78	5	N/A				
Rangefinder–day	1064	12	12	37	47	60	2	N/A				
Rangefinder–night		12	12	37	47	60	5	N/A				
Rangefinder with 12dB filter	1064	3.3	3.3	16	25	31	2	N/A				
AN/PAQ–3 (MULE) (Handheld)	1064								5	3.9	5.6	
Designator–day		20	12	53	64	78	10	N/A				
Designator–night		20	12	53	64	78	15	N/A				
Rangefinder–day	1064	12	12	37	47	60	10	N/A				
Rangefinder–night		12	12	37	47	60	15	N/A				
AN/PAQ–4, A,B,C (IR aiming light)	830	0		0	0	0	0	N/A		0	0	

Table H–2. Nominal ocular hazard distance (atmospheric attenuated), range safety information, and eye protection requirements for man-transportable laser systems (continued)

Device/Mounting		NOHD		NOHD-M			Buffer Zone (Buffer Angle) Each Side		Safety Filters	Required Eye Protection		
	wave-length	multi-pulse	single pulse	7x50 binoc	8-cm optics	12-cm optics	static	moving	built-in[1] or clip-on OD	unaided OD	aided OD	single pulse OD
	nm	kilometers		kilometers			milliradians					
AN/PED–1 (LLDR)												
Rangefinder	1570	0	0	0						0	0	0
Designator	1064	25	16	64/48						5.5	5.5	5.5
AN/PEQ–1 (SOFLAM)	1064	9.6		35	45	54	10	N/A	5	4.0	5.3	
AN/PEQ–2 (ITPIAL)	850									2.0	2.0	
Aiming light & Illuminator		0.263		1.8	2.8	4.7	10	N/A				
Illuminator only		0.211		1.5	2.3	3.9	10	N/A				
Aiming light–high		0.078		0.56	0.88	1.5	10	N/A				
Aiming light–low		0		0	0	0	0	N/A				
AN/PVS-6 (MELIOS)	1540	0		0.007	0.019	0.037	0	0		0	0	
AN/PVS–X (Micro-Laser Rangefinder)	1064		3	16	29	41	90 degrees - 3		Yes	3.7	3.7	
AN/TVQ–2 (G/VLLD) (Tripod)	1064								Yes	3.8	5.5	
Designator		25	17	63	80	87	2	N/A				
Rangefinder		8	8	28.5	40	65	2	N/A				
Rangefinder w/ 8.5dB yellow filter		3.1	3.1	15	23	39	2	N/A				
CLD	1064	9.7		38	48	58	10	N/A	5	4.5	5.4	
LLTD	1064	7		15	38	42	10	N/A		4.0	4.9	
LRAS3	1570	0	0	0						0	0	0

Notes:

[1] Assume the built-in safety filter only protects against the wavelength of the laser in which it is installed and that it does not always protect against other laser wavelengths.

[2] dB–decibels.

Table H–3.
Nominal ocular hazard distance (atmospheric attenuated), range safety information, and eye protection requirements for aircraft-mounted laser systems

Device/Mounting		NOHD		NOHD-M			Buffer Zone (Buffer Angle) each side		Safety Filters	Required Eye Protection		
	wave-length	multi-pulse	single pulse	7x50 binoc	8-cm optics	12-cm optics	static	moving	built-in[1] or clip-on OD	unaided OD	aided OD	single pulse OD
	nm	kilometers		kilometers			milliradians					
Night Targeting System–AH–1W)	1064	15	9.2	48	59	69	5	5	Yes	3.5	5.2	
AN/AAS-33A TRAM (A–6E)	1064	14.6	9	47	58	67	N/A	5		4.6	5.8	3.0
AN/AAS-37 (OV–10D NOS)	1064	11.2	7.1	45	56	59	N/A	5		4.6	5.6	3.0
AN/AAS-38 & 38A (F/A-18A–F)	1064	17	10	50	63	73	N/A	5		4.3	5.4	3.0
AN/ALQ–212 Advanced Threat Infrared Countermeasures		0.016	0.0065	0						1.3		1.3
AN/ASQ–153 PAVE SPIKE (F–4E)	1064	10	6.8	33	48	58	N/A	5		4.2	5.6	
AN/AVQ–25 PAVE TACK (F–111F)	1064	16	8.8	48	52	70	N/A	5		4.3	5.8	
F–117	1064	14	7.5	45	56	65	N/A	TBD	N/A	4.5	6.0	
LAAT (AH-1S & F)	1064	5	3.4	15	30	36	5	5	Yes	3.5	4.8	
LANTIRN (F–14/15/16)[2] combat mode training mode secondary beam[4]	 1064 1540 1064	 15 0 0.35	 9 0 0.35	 48 0.18 2.4	 59 0.32 3.8	 69 0.58 5.44	 N/A 0 N/A	 5[3] N/A N/A	 N/A N/A	 4.5 0 1.1	 5.6 1.2[5] 2.0	
MMS–C (OH–58D) Single pulse Multi-pulse	1064	 35	 23	 56 76	 72 98	 85 119	 5 5	 5 5		4.1	5.3	
NITE Eagle UH–1N	1064	15	11	45	55	65	5	5		4.1	5.2	3.7
Pave Spectre	1064	7.1	4.5	29	38	46	N/A	5	N/A	3.7	5.4	
TADS (AH-64)	1064	26	16	45	68	71	5	5	yes	4.0	5.5	

Table H–3.
Nominal ocular hazard distance (atmospheric attenuated), range safety information, and eye protection requirements for aircraft-mounted laser systems (continued)

Device/Mounting		NOHD		NOHD–M			Buffer Zone (Buffer Angle) each side		Safety Filters	Required Eye Protection		
	wave-length	multi-pulse	single pulse	7x50 binoc	8-cm optics	12-cm optics	static	moving	built-in[1] or clip-on OD	unaided OD	aided OD	single pulse OD
	nm	kilometers		kilometers			milliradians					
AN/AAQ–22 Navigational Thermal Imaging System (UH–1N)	1064		0.72	4	6.1	8.6	5	5	N/A	4.0	4.0	
AC-130U LTD/RF Combat mode Training mode	1064 807	44 9		90 38	110 47	120 56	N/A N/A	55		3.2 1.2	4.8 2.9	
Magic LANTIRN (SH–2F/ MH–53–E)	532	0.15		1.1	1.7	2.6	5	5		5.2	6.7	

Notes:
[1] Assume the built-in safety filter only protects against the wavelength of the laser in which it is installed and that it does not always protect against other laser wavelengths.
[2] For F–15/16, this OD is p; for the F–14, the OD used is 1.2.
[3] Air Force assigned buffer zone is 2 mrad for LANTIRN. Navy F–14 LANTIRN and general policy is that aircraft be assigned a minimum buffer zone of 5 mrad.
[4] Air Force policy is to maintain aircraft separation of 1,000 feet.
[5] Navy prohibits tandem or buddy aircraft lasing.

Table H–4
Nominal ocular hazard distance (atmospheric attenuated), range safety information, and eye protection requirements for ship-mounted laser systems

Device/Mounting		NOHD		NOHD–M			Buffer Zone (Buffer Angle) each side		Safety Filters	Required Eye Protection		
	wave-length	multi-pulse	single pulse	7x50 binoc	8-cm optics	12-cm optics	static	moving	built-in[1] or clip-on OD	unaided OD	aided OD	single pulse OD
	nm	kilometers		kilometers			milliradians					
MMS	1540	0	0	0	0	0	0	0				

Note:
[1] Assume the built-in safety filter only protects against the wavelength of the laser in which it is installed and that it does not always protect against other laser wavelengths.

Table H–5
Nominal ocular hazard distance (atmospheric attenuated), range safety information, and eye protection requirements for commercial-off-the-shelf man-transportable laser systems[1]

Device/Mounting		NOHD		NOHD-M			Buffer Zone (Buffer Angle) each side		Safety Filters	Required Eye Protection		
	wave-length	multi-pulse	single pulse	7x50 binoc	8-cm optics	12-cm optics	static	moving	built-in[2] or clip-on OD	unaided OD	aided OD	single pulse OD
	nm	kilometers		kilometers			milliradians					
AIM–1/D	800-850	0.075		0.46			10	10		1.7	1.7	
AIM–1/DLR	800-850	0.236		1.56	2.43	3.55	10	10		1.7	1.7	
LPL–30	800-850	0.09		0.68	1.1	1.6	10	10		1.7	1.7	
M-931	850	0.011		0.16	0.28	0.4	10	10		0.7	0.8	
GCP–1/1A GCP–1B	800-850	0.09 0.24		0.68 1.65	1.1 2.57	1.6 3.75	10 10	10 10		1.7 2.2	1.7 2.2	
NITE Eye	980	0.09		0.68	1.1	1.6	10	10		1.7	1.7	
HAVIS (M16 Aiming light)	850	0.012		0.1	0.17	0.25	10	10		1.1	1.1	
IZLID II	870	0.248		1.63	2.55	4.28	10	10		3.0	3.0	
TD–100 TD–100A	850 632.8 850 670	0.1					10	10		1.1 0.3 1.1 0.6	1.1 0.3 1.1 0.6	

Notes:
[1] Warning! This hazard data could chance since DOD has no control over manufacturing of these products. Hazard characteristics in this table are valid as of the date of the DOD evaluation; periodically check with the manufacturer to ensure that characteristics have not changed since the date of the last DOD evaluation.
[2] Assume the build-in safety filter only protects against the wavelength of the laser in which it is installed and that it does not always protect against other laser wavelengths.

Table H–6
Nominal ocular hazard distance (atmospheric attenuated), range safety information, and eye protection requirements for commercial-off-the-shelf aircraft-mounted laser systems

Device/Mounting		NOHD		NOHD-M			Buffer Zone (Buffer Angle) each side		Safety Filters	Required Eye Protection		
	wave-length	multi-pulse	single pulse	7x50 binoc	8-cm optics	12-cm optics	static	moving	built-in[1] or clip-on OD	unaided OD	aided OD	single pulse OD
	nm	kilometers		kilometers			milliradians					
AIM–1/MLR	800-850	0.085		0.68	1.1	1.6	5	5		1.7	1.7	
AIM–1/EXL	800-850	0.130		0.68	1.1	1.6	5	5		1.7	1.7	

Note:
[1] Assume the built-in safety filter only protects against the wavelength of the laser in which it is installed and that it does not always protect against other laser wavelengths.

Table H–7
Cautionary distances for eye exposure to weapons simulators and laser training devices

Device/Simulator	Unaided Viewing (m)	Optically Aided Viewing (7 x 50 Binoculars) (m)
MILES I/II Large Gun Simulators	10	0
MILES I SAT pre 1986 Blank Fire	0	0
MILES I SAT pre 1986 Dry Fire	7	0
MILES I SAT post 1986	0	0
MILES 2000 SAT	10	40
MILES 2000 Universal Laser Transmitter	10	40
MILES SWLTU	10	0
M55 Trainer (0.25 s viewing)	0	0
SCOFT	13	160
Schwartz Electro-optic Controller Gun	0	0
AGES/AD TOW	10	0
AGES/AD–Chapparal	0	0
AGES/AD Vulcan	10	0
AGES/AD 2.75” Rocket	10	0
AGES/AD 20 mm Gun	10	0
AGES/AD Stinger	10	438
AN/ASQ–193 LATAGS	0	154
PGTS	0	0
AGES II TADS, MMS and Hellfire Ground Support System Erbium Laser GaAs Laser	 0 0	 0 260
AGES II OH58D Kiowa Warrior 50-Caliber Rocket	 8 6	 22 10
AGES II APACHE 30-mm Advanced Warning System	10	50
TWGSS/PGS Controller Gun (Schwartz E–O) Javelin FFT	o 0 10	5 5 0
AN/GVT–1 Simulated Laser Target With Diffuser Without Diffuser	 0 2760	 0 15,000
ISMT/IST	0	0

APPENDIX I

STANDARDIZATION WITH INTERNATIONAL STANDARDS–INTERNATIONAL ELECTROTECHNICAL COMMISSION 60825–1.1–1998

I–1. Classification guidelines

a. The classification guidelines and controls set forth in this document emulate those established in ANSI Z136.1. The ANSI Z136 Committee has always strived to have a standard that is as close to identical as possible with the Federal Laser Product Performance Standard, issued by the CDRH, and the international standard for laser safety issued by the International Electrotechnical Commission (IEC 60825 series).

b. There are currently few differences between the standards. At the time of the publication of ANSI Z136.1–2000, the revised FLPPS had not been published as a final rule, but the classification system applied in the revised standard was to be harmonized with the IEC guidelines.

I–2. Federal Laser Product Performance Standard and the American National Standards Institute

a. In the past, the FLPPS and the ANSI standards did not always consider optically aided viewing of a highly diverging beam (for example, from a diode laser or fiber pigtail source). Such a highly diverging beam could be collected by an eye loupe and rendered more hazardous. This concern was not previously considered in the development of earlier ANSI standards except in ANSI Z136.2. Safety requirements should be increased when there are increased optical hazards due to individuals using optical aids. However, safety requirements would not have to be increased when the use of optical aids is not expected.

b. The IEC standard now recommends that all lasers of very low risk and "safe under reasonably foreseeable use" be placed into Classes 1 and Class 1M. Under this classification scheme, Class 1 is “eye safe” under all viewing conditions and Class 1M are “eye safe” except when viewed with optical aids. The same considerations are made for Class 2 lasers (that is visible wavelength (400 nm–700 nm) emitting lasers), which pose a low risk. (Note: The term “eye safe” in reference to laser use and application is used by the IEC to connote Class 1. Because this term has frequently been misused in the United States to refer to “eye-safe” laser wavelengths in the middle infrared spectrum and not solely to Class 1, the ANSI Z136 committee avoids the use of this term when discussing lasers and potential laser hazards at this time.)

c. Due to the aversion response of the eye, Class 2 lasers are safe for momentary viewing under all conditions, and Class 2M are safe for momentary viewing only without optical aids. The IEC Technical Committee 76 (IEC TC 76, Optical Radiation Safety and Laser Equipment) then created a transitional zone, Class 3R (“R” for Reduced Requirements). This new class will mainly consist of lasers previously classified in ANSI as Class 3a, CDRH as Class IIIA, and IEC as Class 3B lasers emitting less than 5 mW. At first glance, these changes appear to be extensive. In truth, very few laser products are affected. Only laser products with greatly expanded beams or highly diverging beams are affected. Almost all Class 1 lasers remain Class 1 and almost all Class 2 products (those with small beam diameters) remain Class 2 in the revised system. Virtually, all of the lasers currently classified as Class 3a will become Class 3R. There is no requirement to reassess lasers that were previously classified. However, a laser product with a highly diverging or greatly expanded beam that may have been "over-classified" by the old system can be reclassified according to this updated classification scheme.

I–3. International Electrotechnical Commission

a. The advantages of the IEC revision in 2001 were that the same classification time base is now used within each group, and the revised classification scheme became more versatile for application (vertical) standards where controls may differ based upon risk.

b. Additionally, common risk concepts are applied for each class, and the revised scheme became easier to teach in laser safety classes.

Table I–1
Comparison of classification schemes

Class	IEC 60825 (Amend. 2)	U.S. FDA/CDRH	ANSI Z136.1 (2000)
Class 1[1]	Any laser or laser system containing a laser that cannot emit laser radiation at levels that are known to cause eye or skin injury during normal operation. This does not apply to service periods requiring access to Class 1 enclosures containing higher-class lasers.		
Class 1M[2]	Not known to cause eye or skin damage unless collecting optics are used.	N/A	N/A
Class 2a[3]	N/A	Visible lasers that are not intended for viewing and cannot produce any known eye or skin injury during operation based on a maximum exposure time of 1000 seconds.	N/A
Class 2[4]	Visible lasers considered incapable of emitting laser radiation at levels that are known to cause skin or eye injury within the time period of the human eye aversion response (0.25 s).		
Class 2M[5]	Not known to cause eye or skin damage within the aversion response time unless collecting optics are used.	N/A	N/A
Class 3a[6]	N/A	Visible lasers that cannot emit more than 5 mW for time periods greater than 0.38 ms.	CAUTION Lasers that do not exceed the MPE for the unaided eye, but exceed the MPE by no more than 5 times with the use of optical viewing aids. DANGER Lasers that exceed the MPE by no more than 5 times, with or without the use of optical viewing aids and includes lasers with non-visible wavelengths that exceed the MPE by no more than 5 times.
Class 3R[7]	Replaces Class 3a and has different limits. Up to 5 times the Class 2 limit for visible and 5 times the Class 1 limits for some invisible wavelengths.	N/A	N/A

Table I–1
Comparison of classification schemes (continued)

Class 3b[8]	Medium-powered lasers (visible or invisible regions) that present a potential eye hazard for intrabeam (direct) or specular (mirror-like) conditions. Class 3b lasers do not present a diffuse (scatter) hazard or significant skin hazard except for very high-power Class 3b lasers operating at certain wavelength regions.
Class 4	High-powered lasers (visible or invisible) considered to present potential acute hazard to the eye and skin for both direct (intrabeam) and scatter (diffused) conditions. Also have potential hazard considerations for fire (ignition) and byproduct emissions from target or process materials.

[1] All former Class 1 lasers are still Class 1.
[2] Former Class 3a or Class 3b lasers that did not present an unaided viewing hazard are now Class 1M.
[3] Class 2a lasers are now Class 1 lasers.
[4] All former Class 2 lasers are still Class 2.
[5] Former Class 3a or Class 3b visible lasers that did not present an unaided viewing hazard for less than 0.25 s are now Class 2M.
[6] Former Class 3a lasers are now Class 3R lasers.
[7] The Class 3R designation replaces the Class 3a designation. Class 3a expanded-beam lasers are rare outside military applications and are now Classes 1M and 2M.
[8] Most former Class 3b systems are now Class 3B systems with the exception of some expanded beam lasers that now are classified as either Class 1M or Class 2M.

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GLOSSARY

Section I
Acronyms

ACGIH
American Conference of Governmental Industrial Hygienists

AED
automated external defibrillator

AEL
accessible emission limit

AGES/AD
Air to Ground Engagement System/Air Defense

AIM
Advanced Infrared Module

ANSI
American National Standards Institute

AN/VVG
Army/Navy/Ground Vehicular Visible Light

AR
Army Regulation

BLPS
Ballistic and laser protection spectacles

CDRH
Center for Devices and Radiological Health

CFR
Code of Federal Regulation

CLD
Compact Laser Designator

cm
centimeter(s)

cm^2
square centimeter(s)

COTS
commercial off-the-shelf

CPR
cardiopulmonary resuscitation

CW
continuous wave

DA
Department of the Army

DA Pam
Department of the Army Pamphlet

DMSO
dimethylsulfoxide

DOD
Department of Defense

DODI
Department of Defense Instruction

ESSLR
Eye Safe Simulated Laser Rangefinder

FAA
Federal Aviation Administration

FATS
Fire Arms Training Systems

FDA
Food and Drug Administration

FLIR
Forward looking infrared

FLPPS
Federal Laser Product Performance Standard

FM
Field Manual

FS3
Fire Support Sensor System

FTT
field tactical trainer

GCP
Ground Commander's Pointer

GLPS
Gun Laying and Positioning System

GTL
gas transport laser

HCLS
Healthcare Laser System

HCP
healthcare personnel

HGU
head gear unit

HIOS
high intensity optical source

HLONS
High-Energy Laser Ordnance Negation System

HMMWV
high-mobility multipurpose wheeled vehicle

Hz
hertz

IEC
International Electrotechnical Commission

IESNA
Illuminating Engineering Society of North America

IR
infrared

IR-A
near infrared radiation (700 nm–1400 nm)

IR-B
midrange infrared radiation (1400 nm–3 µm)

IR-C
far infrared radiation (3 µm–1000 µm)

ISMT
Indoor Simulated Marksmanship Trainer

IST
Infantry squad trainer

ITPIAL
Infrared Target Pointer and Illuminator and Aiming Laser

IZLID
Infrared Zoom Laser Illuminator/Designator

J
Joule(s)

JP
Joint Publication

kHz
kilohertz

km
kilometer(s)

LAAT
Laser Augmented Airborne Tube Launched, Optically Tracked, Wire (TOW)

LANTIRN
Low Altitude Navigation Targeting Infrared for Night

LATAGS
Laser Air to Air Gunnery System

LAV
Light Armored Vehicle

LD
Laser designator

LDM
Laser designator module

LGAC
Laser-generated air contaminants

LLDR
Lightweight Laser Designator Rangefinder

LORP
Laser/Optical Radiation Program

LRAS3
Long Range Advanced Scout Sensor System

LRF
laser rangefinder

LRSNCO
Laser Range Safety Noncommissioned Officer

LRSO
Laser Range Safety Officer

LRSO/LRSNCO
Laser Range Safety Officer/Laser Range Safety Noncommissioned Officer

LRSO/NCO
Laser Range Safety Officer/Noncommissioned Officer

LSDZ
laser surface danger zone

LSO
Laser Safety Officer

LSSO
Laser System Safety Officer

LTD
Laser target designator

m
meter(s)

MELIOS
Mini-Eyesafe Laser Infrared Observation Set

MEPS
Military Eye Protection System

MH_z
megahertz

MILES
Multiple Integrated Laser Engagement System

MIL–HDBK
Military Handbook

MIL–STD
Military Standard

mJ
milliJoule(s)

mL
milliliter(s)

MLR
Mini-Laser Range

MLRF
Mini-Laser Rangefinder

mm
millimeter(s) (1×10^{-3} meter(s))

MMS
Mast-Mounted Sight

MPE
maximum permissible exposure

mrad
milliradian(s)

ms
millisecond(s)

m/s
meters per second

MSDS
Material Safety Data Sheet

MSMC
Main Support Medical Company

MTF
Military treatment facility

MULE
Modular Universal Laser Equipment

mW
milliWatt(s)

Nd:YAG
Neodymium:Yittrium Aluminum Garnet

NEC
National Electrical Code

NFPA
National Fire Protection Association

NG
National Guard

NHZ
nominal hazard zone

NIOSH
National Institute for Occupational Safety and Health

NIR
near infrared

nm
nanometer(s) (1×10^{-9} meter(s))

NMMS
Navy Mast-Mounted Sight

NMR
nuclear magnetic resonance

NOHD
Nominal ocular hazard distance

NOHD–M
Nominal ocular hazard distance-magnifying

ns
nanosecond(s)

NSN
National Stock Number

NTIS
Navigational thermal imaging system

NTS
Night targeting system

NVG
night vision goggle

nW/cm^2
nanoWatt per square centimeter(s)

OD
optical density

OSHA
Occupational Safety and Health Administration

PCM
pulse-code modulation

PD_{req}
required optical

PEL
permissible exposure limit

PGS
Precision Gunnery System

PGTS
Precision Gunnery Training System

PPE
personnel protective equipment

PRF
pulse repetition frequency

ps
picosecond (1×10^{-12}s)

rad
radian(s)

RF
rangefinder

RFR
radiofrequency radiation

RSO
Radiation Safety Officer

s
second(s)

SAT
small-arms transmitter

SCOFT
Shillelah Conduct of Fire Trainer

SOFLAM
Special Operations Forces laser marker

SOP
standing operating procedure

SPECS
special protective eyewear, cylindrical system

SPH
Sound protective helmet

SR
Simulated round

sr
steradian(s)

STANAG
standardization agreement

SWDG
Sun, wind, and dust goggles

TADS/PNVS
Target Acquisition and Designation System with Pilot Night Vision Sight

TB MED
Technical Bulletin, Medical

TD
Target designator

TEM
transverse electromagnetic mode

TLOS
Target Location and Observation System

TLV
threshold limit value

TOW
Tube launched, optically tracked, wire guided

TVCRP
Tri-Service Vision Conservation and Readiness Program

TWGSS
Tank Weapon Gunnery Simulator System

UH
Utility helicopter

USACHPPM
U.S. Army Center for Health Promotion and Preventive Medicine

USAMRD
U.S. Army Medical Research Detachment

UV
ultraviolet (100 nm–400 nm)

UV-A
ultraviolet radiation (315 nm–400 nm)

UV-B
ultraviolet radiation (280 nm–315 nm)

UV-C
ultraviolet radiation (100 nm–280 nm)

UVR
Ultraviolet radiation

VA
visual acuity

W
Wa(s)

WRAIR
Walter Reed Army Institute of Research

µJ
microJoule(s)

µm
micrometer(s)

µs
microsecond(s)

µW
microwatt(s)

Section II
Terms

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 class.

accessible radiation
Radiation to which it is possible for the human eye or skin to be exposed in normal usage.

aided viewing
Viewing a laser with magnifying optical aids such as binoculars, telescopes, and eye loops, which increases the NOHD by roughly the magnifying power of the optics, ignoring transmission losses through the optics and atmospheric attenuation. Eye loops should not be included in the hazard calculations unless they are definitely being used.

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

α_{min}
See limiting angular subtense.

ambient light
Light present in the environment around a detecting or interpreting device, generated from outside sources. Such light must be treated as noise by the detector.

aperture
An opening or hole through which radiation or matter may pass.

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

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

aversion response
Closure of the eyelid or movement of the head to avoid an exposure to a noxious stimulant or bright light. In this standard, the aversion response to an exposure from a bright laser source is assumed to occur within 0.25 s, including the blink reflex time.

beam
A collection of rays which may be parallel, divergent, or convergent.

beam attenuator
A device designed to decrease flux density or power per unit area of a light beam through absorption and scattering of the beam.

beam diameter (D_L)
a. Calculated distance between two exactly opposed points on a beam at a chosen fraction of peak power.
b. The diameter of a circular aperture that will pass a specified percentage (usually 63 percent) of the total beam energy. 3. The distance between diametrically opposed points in that cross section of a beam where the power per unit area is l/e (0.368) times that of the peak power per unit area.

beam divergence ϕ
See divergence.

beam stop
A device which terminates a laser beam path.

blink reflex
See aversion response.

buffer angle
The angle about the laser's line-of-sight with apex at the laser aperture that is used to determine the buffer zone. As a minimum, it is typically set to five times the demonstrated pointing accuracy of the system plus the beam divergence. (Buffer angles for several lasers are assigned in table H–1.)

buffer zone
A conical volume centered on the laser's line-of-sight with its apex at the aperture of the laser, within which the beam will be contained with a high degree of certainty. The buffer zone is determined by the buffer angle.

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

C_B
Correction factor which increases the MPE values in the red end of the visible spectrum (550 nm–700 nm) due to greatly reduced photochemical hazards.

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

C_E
Correction factor used for calculating the extended source MPE for the eye from the intrabeam MPE, when the laser source subtends a visual angle exceeding α_{min}.

C_P
Correction factor that reduces the MPE for repetitively pulsed exposure of the eye.

collateral radiation
Any electromagnetic radiation, except laser radiation, emitted by a laser or laser system that is physically necessary for its operation. Extraneous radiation (such as secondary beams from optics, flash lamp light, radiofrequency radiation, x-rays, and so forth) that is not the intended laser beam as a result of the operation of the product or any of its components. System indicator lights would not normally be considered sources of collateral radiation.

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

cone angle
The acute angle between the cone perimeter and its axis.

conjunctiva
The mucous membrane that lines the inner surface of the eyelids and is continued over the forepart of the eyeball.

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

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

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

dielectric
Characteristic of materials that are electrical insulators or in which an electric field can be sustained with a minimum dispersion of power. They exhibit nonlinear properties such as anisotropy of conductivity or polarization or saturation phenomena.

diffraction
a. Refers to the bending of a light ray as the light passes through a small hole in a barrier or passes by the edge of a small barrier.
b. Deviation of part of a beam, determined by the wave nature of radiation and occurring when the radiation passes the edge of an opaque obstacle.

diffuser
A device used to scatter or disperse light emitted from a source, usually by the process of diffuse transmission.

diffuse reflection
Reflection from a surface in which the beam is scattered in all directions (for example, a non-specular reflection from a rough surface). An ideal diffuse surface in which reflected brightness is independent of the viewing angle is called a Lambertian surface.

diffuse reflector
A reflecting surface that scatters radiation that is incident on it, thus producing diffuse reflection.

divergence (ϕ)
The full angle width of the laser beam measured between the two points at which laser radiant exposure or irradiance in the laser beam is equal to 1/e (36.8 percent) of the maximum value. Put another way, beam divergence is the increase in the diameter of an initially collimated beam, or the angle of beam spread measured in radians or milliradians (1 mrad = 3.4 minutes of arc or approximately 1 mil).

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

embedded laser
An enclosed laser with an assigned class number higher than the inherent capability of the laser system in which it is incorporated, where the systems lower classification is appropriate due to the engineering features limiting accessible emission.

emergent beam diameter (a)
Diameter of the laser beam at the exit aperture of the system in centimeters; for a Gaussian beam, the diameter at 1/e peak intensity values.

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 removal of the protective housing provides additional access to laser radiation above the applicable MPE than possible with the protective housing in place. (An embedded laser is an example of one type of enclosed laser.)

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

erythema
Redness of the skin due to congestion of the capillaries, as in inflammation (that is, sunburn).

exposure limit
The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin.

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

far-infrared radiation
That radiation composed of the wavelengths falling between light and microwaves, ranging from about 3 µm to 1000 µm (IR–C). (See infrared radiation, IR–C.)

filter
With respect to radiation, a device used to attenuate particular wavelengths or frequencies while passing others with relatively no change.

gas laser
A type of laser in which the laser action takes place in a gas medium, usually operated as a CW laser.

Gaussian Beam
A beam of light whose electrical field amplitude distribution is gaussian. When such a beam is circular in cross-section, the amplitude is $E(r) = E(0)^{\left[-\left(r/w\right)^2\right]}$, where r is the distance from beam center and w is the radius at which the amplitude is 1/e of its value on the axis; 2w is the beam diameter.

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

hot spot
Term applied to a laser beam to denote areas within the beam of above average intensity often attributable to atmospheric inconsistencies.

illuminance
The measurement of how bright a point source of light appears to the eye. It is measured in foot-candles.

infrared radiation
Electromagnetic radiation, invisible to the human eye, with wavelengths from 700 nanometers to 1 millimeter. This region is often divided into three spectral bands by wavelength: IR–A (700 nm–1400 nm), IR–B (1400 nm–3000 nm), and IR–C (3 µm–1000 µm). IR–A is sometimes called near-infrared, produces a sensation of heat.

integrated radiance
A synonym for pulsed radiance. The integral of the radiance over the exposure duration. Also known as pulsed radiance. Unit: Joules per square centimeter per steradian ($J\text{-}cm^{-2}\cdot sr^{-1}$).

interference
The phenomenon that results when two or more waves of the same type for example, light waves, pass simultaneously through the same point(s) and form a combined wave.

interlock
A mechanical device designed to disconnect electrical power to the laser system or to stop the laser beam from exiting the laser housing when the interlock is opened. These are found on Class 3b and Class 4 laser system housings and at the doors of laser facilities where the NHZ extends to the door and other control measures will not prevent injury to one entering the facility. Medical laser facilities (that is, operating rooms) are exempt from having door interlocks.

intrabeam viewing
a. With respect to laser radiation, the subjection of the human eye to all or a portion of the laser beam.
b. The viewing condition where the source subtends an angle at the eye that is equal to or less than α_{min}, the limiting angular subtense. This category includes most collimated beams and so called point sources.

inventory
An inventory of all Class 3b (and Class IIIb) lasers and above should be maintained by the LSO. The inventory should include information on the laser class, type, wavelength, power or energy, location, and point of contact. The inventory should be maintained and updated on a regular basis.

ionizing radiation
Electromagnetic radiation having a sufficiently large photon energy to directly ionize atomic or molecular systems with a single quantum event.

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

irradiance (power density, E)

a. Radiant flux incident per unit area of a surface: radiant incidence.

b. At a point of a surface, the quotient of the radiant power dΦ incident on an element dA of a surface containing the point by the area to that element.

$$E = \frac{\partial P}{\partial A} \qquad \left[\frac{W}{cm^2}\right]$$

J·cm^{-2} or J/cm^2
A unit of radiant exposure used in measuring the amount of energy-per-unit-area of absorbing surface or per unit area of a laser beam.

Joule
A unit of energy (1 Joule = 1 Watt second or 0.239 calories used normally in describing a single pulsed output of a laser.

lambertian surface
An ideal surface whose emitted or reflected radiance is independent of the viewing angle.

laser-controlled area
Any location or area where there are one or more lasers and where activity of personnel is subject to control and supervision for the protection from radiation hazards associated with laser operation.

laser eyewear
Usually consists of a set of filters that attenuate specific wavelengths but transmit as much visible radiation as possible.

laser footprint
The projection of the laser beam and buffer zone onto the ground or target area. The laser footprint may be part of the laser surface danger zone if the laser footprint lies within the NOHD of the laser.

laser radiation
All electromagnetic radiation emitted by a laser product in the optical spectral range that is produced as a result of controlled stimulated emission.

Laser Range Safety Officer/Noncommissioned Officer (LRSO/NCO)
Direct representative of the individual in charge of laser operations; individual can be either a qualified civilian or military person.

Laser Safety Officer/Radiation Safety Officer (LSO/RSO)
An individual trained in laser safety that has authority (appointed by the commander) to monitor and enforce the control of laser hazards and affect the knowledgeable evaluation and control of the

hazards associated with lasers at a particular installation. The term Laser System Safety Officer in the Navy differentiates the LSSO from the Landing Signal Officer. Each Service's regulations stipulates training requirements for LSOs/LSSOs and may differentiate among—

a. Laser safety consultants. Service experts who evaluate and advise on laser safety.

b. Base laser safety officer. Responsible for paperwork, administration, safety training and compliance inspections at the installation (for example, Air Force Bio-Environmental Engineer, Army Radiation Protection Officer, Navy Base Safety Officer).

c. Unit laser safety officer. The individual in the laser user's chain of command who is responsible for all laser issues at the operational level. It includes but is not limited to: establishing unit-specific laser regulations and procedures and ensuring compliance to the appropriate laser regulations and restrictions of the host facility that the appropriate operational and safety training for the laser weapon shall be used, maintaining unit laser accountability, and ensuring that all other unit related laser safety issues are addressed.

d. Installation range laser safety officer. One who has the physical control of the Laser Range and is responsible for its use; including but not limited to: (1) establishing range specific laser safety regulations and procedures, and (2) ensuring that all users comply with all appropriate laser safety regulations in place at the range. The Range Laser Safety Officer may be from the range installation or a visiting Unit Laser Safety Officer.

Laser Safety Program
The laser safety program is usually an extension of the Non-Ionizing Radiation Protection Program, which itself is a component of the overall radiation protection program

Laser Surface Danger Zone (LSDZ) or Nominal Hazard Zone (NHZ)
The designated region or ground area where laser radiation levels may exceed the MPE levels, thereby, requiring control during laser operation. Unauthorized personnel are not permitted, and laser eye protectors are required for personnel who may engage in intrabeam viewing within this area.

laser test set
A set of equipment configured to a laser system in order to test the laser’s parameters.

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

light
Visible radiation (400 nm to 700–780 nm). For the purposes of this bulletin, limited to wavelengths between 400 nm–700 nm.

Light amplification by stimulated emission of radiation (Laser)
A cavity, with plane or spherical mirrors at the ends, that is filled with lasable material. This is any material, crystal, glass, liquid, dye or gas, the atoms of which are capable of being excited to a semi-stable state by light or an electric discharge. The light emitted by an atom as it drops back to the

ground state releases other nearby, excited atoms, the light being thus continually increased in intensity as it oscillates back and forth between the mirrors. If one mirror is made to transmit 1 or 2 percent of the light, a brilliant beam of highly monochromatic, coherent radiation is emitted through the mirror. If plane mirrors are used, the beam is highly collimated. With concave mirrors the beam appears to emerge from a point source near one end of the cavity.

limiting aperture (D_f)
The maximum diameter of a circle over which irradiance and radiant exposure can be averaged.

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

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

maximum permissible exposure (MPE)
The level of laser radiation to which a person may he exposed without hazardous effect or adverse biological changes in the eye or skin. Laser radiation exposure levels published in ANSI Z136.1 and established for the protection of personnel. The MPEs contained in ANSI Z136.1 are used in this handbook and are in concurrence with STANAG 3606.

meter
A unit of length in the international system of units; currently defined as a fixed number of wavelengths, in vacuum, of the orange-red line of the spectrum of krypton 86. Typically, the meter is subdivided into the following units:

a. Centimeter (cm) = 10^{-2} m.
b. Millimeter (mm) = 10^{-3} m.
c. Micrometer (μm) = 10^{-6} m.
d. Nanometer (nm) = 10^{-9} m.

micrometer (μm, micron)
Formerly termed micron, a measure of length equal to 10^{-6} m.

milliradian (mrad)
Unit of angular measure. One mrad equals one thousandth of a radian. One degree equals 17.5 milliradians.

mode-locked laser
A laser that functions by modulating the energy content of each mode internally to give rise selectively to energy bursts of high-peak power and short duration in the picosecond domain.

monochromaticity
Literally means "one color" or, to be more technically correct, "one wavelength."

n
Number of pulses.

nanometer (nm)
Unit of length equal to 10^{-9} m. Sometimes termed millimicron.

near-infrared
The shortest wavelengths of the infrared region, nominally 700 nm–1400 nm (IR–A).

Neodymium:YAG (Nd:YAG)
A cylindrical rod of yttrium-aluminum-garnet doped with neodymium that is the active medium of the Nd:YAG laser, a highly serviceable solid-state device.

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

nominal ocular hazard distance (NOHD)
The distance along the axis of the unobstructed beam from the laser to the human eye beyond which the irradiance or radiant exposure during operation is not expected to exceed the appropriate MPE; that is, the safe distance from the laser. The NOHD-magnifying is the NOHD when viewing with optical aids.

normal
An axis that forms right angles with a surface or with other lines. The normal is used to determine incident, reflective, and refractive angles.

normal incidence
Light striking a surface at an angle perpendicular to the surface.

ocular fundus
The back of the eye. May be seen through the pupil with an ophthalmoscope.

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.

optical density (D_λ or OD)

a. Logarithm to the base ten of the reciprocal of the transmittance: $D_\lambda = -\log_{10}\tau_\lambda$, where τ_λ is transmittance.

b. A logarithmic expression for the attenuation produced by an attenuating medium, such as an eye protection filter, $OD = \log_{10} \Phi_0/\Phi_t$, where Φ_o is the incident power and Φ_t is the transmitted power at a specific wavelength.

optical radiation

Electromagnetic radiation with wavelengths between 180 nm to 1 millimeter (mm). This radiation is often divided into three spectral regions by wavelength: ultraviolet radiation (180 nm–400 nm), visible radiation (400 nm–700 nm), and infrared radiation (700 nm–1 mm).

optical spectral range

Wavelength range between 100 nm and 1 mm of the electromagnetic radiation.

photoablation

Target tissue is photolytically dissociated and volatilized by short-pulsed (nanosecond) ultraviolet radiation to give incisions with no visible necrosis and no hemostasis.

photon

A packet of electromagnetic energy, a "particle" of light. Atoms and molecules emit and absorb energy in single units called "photons." The energy of a single photon is proportional to the frequency of the emitted light wave.

p-n junction

The combination of N-type and P-type semiconductors together in very close contact. The term junction refers to the region where the two types of semiconductor meeting. It can be thought of as the border region between the P-type and N-type blocks.

pigment epithelium (of the retina)

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

point source (of optical radiation)

a. A source of radiation whose dimensions are small enough, compared with the distance between source and receptor, to be neglected in calculations.

b. A source of radiation whose dimensions are small enough to result in a subtended angle that is less than α_{min}. For the purpose of this standard, a point source leads to intrabeam viewing conditions.

population inversion

Refers to the artificial and energetically unstable situation where at some instant more atoms (or ions or molecules) are in a given excited state than in a lower energy state.

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

power density (irradiance)
Perhaps the single most important parameter in determining the effect of a laser is the ratio of the laser power striking the target divided by the cross sectional area of the laser beam. It is usually measured in watts per square centimeter $W{\cdot}cm^{-2}$.

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

pulse duration (t)
The lifetime (duration) of a laser pulse generally defined as the time interval between the half-peak-power points on the leading and trailing edges of the pulse. The unit of pulse duration is the second.

pulse repetition frequency (PRF)
The number of pulses emitted in a given time period or the reciprocal of the time between the pulses. The unit of prf is the hertz (Hz, l/s).

pulse width
See pulse duration.

pulsed laser
a. A laser that delivers its energy in the form of discontinuous bursts, a single pulse or a group (train) of pulses; that is, there are time gaps during which no energy is emitted. For the purpose of this document, a laser that emits a pulse for less than 0.25 second.
b. A laser that emits energy in a wave of short bursts or pulses, and that remains inactive between each burst or pulse. The frequency of the pulses is termed the pulse repetition frequency.

pulsed radiance
The integral of the radiance over exposure time.

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

Q-switch
A device for producing very short (10 ns–250 ns), 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 ns - 250 ns), high-power pulses by means of a Q-switch.

Q-switched pulse
A laser output that occurs when the cavity resonator Q is first kept very low, using rotating mirrors or saturable absorbers, so that the population inversion achieved is greater than usual. A high intensity, short pulse of coherent radiation is emitted when the Q is raised to its normal value.

radian
a. The unit angle, within an arc of a circle, equal to the radius of the circle (180/π degrees, numerically).
b. 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 (radian = 57.3 degrees; 2π radians = 360 degrees).

radiance
Radiant flux or power output per unit solid angle per unit area. Unit: Watts per centimeter squared per steradian ($W \cdot cm^{-2} \cdot sr^{-1}$).

radiant energy
Energy (in the form of electromagnetic waves) emitted, transferred, or received in the form of radiation. Unit: Joule. Commonly used to describe the output of pulsed lasers.

radiant exposure (H)
a. Surface density of the radiant energy received. It expresses exposure dose to pulsed laser radiation.
b. At a point on a surface, the radiant energy incident on an element of a surface divided by the area of that element—

$$H = \frac{dQ}{dA} = \int E \bullet dt \quad \left(\frac{J}{cm^2}\right)$$

radiant flux or radiant power
a. Power emitted, transferred, or received in the form of radiation. Unit: Watt.
b. The time rate of flow of radiant energy measured in watts. The prefix is often dropped, and the term "power" used—

$$\Phi = \frac{dQ}{dt} \quad (W)$$

radiant power
See radiant flux.

Radiation Protection Program
Encompasses all of the radiation protection programs including non-ionizing and ionizing components.

Radiation Safety Officer (RSO)
Person in charge of all radiation safety and protection measures for a site or installation. Previously referred to as Radiation Protection Officer.

reflectance or reflectivity
The ratio of total reflected radiant energy (power) to total incident energy (power).

reflection
Deviation of radiation following incidence on a surface.

refraction
The bending of a light ray as the light passes from one material into another.

repetitively pulsed laser
A laser with multiple pulses of radiant energy occurring in a sequence; in other words, a pulsed laser with a sequentially recurring pulsed output. Frequency of the pulses emitted is known as PRF. When the PRF or duty cycle is very high, repetitively pulsed lasers illustrate properties like those of the CW laser.

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

ruby laser
The optically pumped, solid-state laser that uses sapphire as the host lattice and chromium as the active ion. The emission of the laser takes place in the red portion of the spectrum.

saturation
The decrease of the absorption (or gain) coefficient of a medium near some transition frequency when the power of the incident radiation near that frequency exceeds a certain value. As long as the absorption (or gain) coefficient is constant, the power absorbed (or emitted) by the medium is proportional to the incident power. However, there is always a limit to the rate at which the medium can absorb (or emit) power that is determined by the lifetimes of the energy levels involved. As this limit is reached, the induced transitions become rapid enough to affect the energy level populations, making them more nearly equal.

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

scintillation
a. In optics, a light flash formed by an ionizing event in a phosphor; a flash formed when rapidly traveling particles, such as alpha particles, travel through matter.
b. The rapid changes in irradiance levels in a cross-section of a laser beam. In laser work, this term is frequently used to describe the effect upon a laser beam by atmospheric turbulence.

scotoma
Loss of vision in part of the visual field; blind spot.

semiconductor
A class of lasers that produce relatively low average power outputs.

shutter
A mechanical or electronic device used to control the amount of time that a light-sensitive material is exposed to radiation.

solid angle (Ω)
a. The ratio of the area on the surface of a sphere to the square of the radius of that sphere. It is expressed in steradians (sr).
b. 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-state laser
A laser using a transparent substance (for example, crystalline or glass) as the active medium, doped to provide the energy states necessary for lasing. The pumping mechanism is the radiation from a powerful light source, such as a flash lamp. The ruby and Nd:YAG lasers are solid-state lasers.

spectrum
The pattern of wavelengths of light emitted or absorbed by a particular source. For example, each different element emits (and absorbs) its very specific and unique pattern of wavelengths.

steradian (sr)
a. The unit of measure for a solid angle, often used in problems of illumination. There are 4π steradians about any point in space.
b. The unit solid angle subtended at the center of a sphere by an area on its surface equivalent to the square of the radius. If a pure cone, a steradian subtends a solid angle of about 66 degrees.

support equipment
Devices or enclosures procured specifically for, or modified for, laser test, calibration, maintenance, or other support not part of the primary laser mission.

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

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

T_{max}
See limiting exposure duration.

t_{min}
For a pulsed laser, the maximum time duration for which the MPE is the same as the MPE for a 1 ns exposure.

transmission
Passage of radiation through a medium.

transmittance or transmissivity
The ratio of total transmitted radiant power to total incident radiant power.

ultraviolet radiation (UVR)
Electromagnetic radiation with wavelengths smaller than those of visible radiation, and larger than soft X-rays. For the purpose of this standard, 100 nm–400 nm. UV can be subdivided into three spectral regions—

a. UV–A (315 nm–400 nm). Often called Black Light, most phototherapy tanning booths have UV–A Lamps. UV–A has a limited potential for erythemal (sunburn) effects.

b. UV–B (280 nm–315 nm). Typically, the most destructive form of UV light, a known carcinogen, and used in many phototherapy booths under controlled conditions. UV–B has a high potential for erythemal effects. UV–B can be and is used in germicidal lamps.

c. UV–C (100 nm–280 nm). UV–C is highly absorbed in air, an ozone producer and can be used in germicidal lamp systems.

unaided viewing
Viewing a laser with the naked eye or corrected vision using lenses such as spectacles, glasses or contacts.

vaporization
Used for incising or excising and occurs at temperatures over 100 degrees Celsius in tissue with a high water content.

visible radiation (light)
Electromagnetic radiation which can be detected by the human eye. This term is commonly used to describe wavelengths that lay in the range 400 nm–700 nm.

Watt
a. The power that gives rise to the production of energy at the rate of one Joule per second.
b. The unit of power or radiant flux. 1 Watt = 1 Joule per second. Used principally with CW lasers.

Watt·cm^{-2} (W·cm^{-2}) or W/cm^{2}
A unit of irradiance used in measuring the amount of power-per-area of absorbing surface, or cross-sectional area of a CW laser beam.

wavelength (λ)
a. The distance between two successive points on a periodic wave that have the same phase is termed 1 wavelength. The velocity of light (3 X 10^{-10} cm/s) divided by frequency (in Hz) equals wavelength (in cm).
b. The distance measured along the direction a wave is traveling, during which the wave pattern repeats itself (for example, the distance from one wave crest to the next wave crest). Red light, for instance, has a longer wavelength than blue light.

Section III
Special Abbreviations and Terms
This section contains no entries.

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