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DEPARTMENT OF THE ARMY TECHNICAL BULLETIN

OCCUPATIONAL AND ENVIRONMENTAL HEALTH

CONTROL OF HAZARDS TO HEALTH FROM LASER RADIATION

HEADQUARTERS, DEPARTMENT OF THE ARMY

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OCCUPATIONAL AND ENVIRONMENTAL HEALTH

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CHAPTER 2

EFFECTS OF LASER EXPOSURE

Section I. BIOLOGIC EFFECTS

2–1. General. 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 biologic effects of laser radiation are essentially those of visible, ultraviolet, or infrared 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 lights. This is one of the important properties that make lasers potentially hazardous. Laser radiation incident upon biologic tissue will be reflected, transmitted, and/or absorbed. The degree to which each of these effects occurs depends upon various properties of the tissue involved. Absorption is selective: as in the case of visible light, darker material such as melanin or other pigmented tissue absorbs more energy.

2–2. Skin. Adverse thermal effects resulting from exposure of the skin to radiation from 315 nm to 1mm may vary from mild reddening (erythema) to blistering and charring. This depends upon the exposure dose rate, the dose (amount of energy) transferred, and the conduction of heat away from the absorption site. Adverse skin effects resulting from exposure to actinic ultraviolet radiation (180 to 315 nanometers (nm)) vary from erythema to blistering, depending upon the wavelength and total exposure dose.

2–3. Eye.

a. General.

(1) In almost all situations the eye is the organ most vulnerable to injury. Figure 2–1 provides a schematic representation of absorption of electromagnetic radiation by the eye:

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

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

(*c*) Near ultraviolet (UV-A) radiation is primarily absorbed in the lens.

(*d*) Light is refracted at the cornea and lens and absorbed at the retina; near infrared (infrared-"A") (IR-A) radiation is also refracted and is absorbed in the ocular media and at the retina.

(2) Refer to paragraph 3–23 for a discussion on laser protective eyewear.

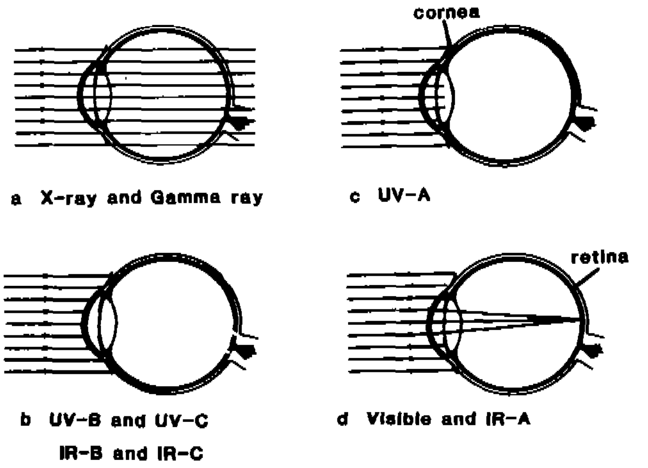


Figure 2–1. Absorption of electromagnetic radiation by the eye.

b. Light (400-760 nm) and near-infrared (IR-A) radiation (>760-1400 nm) (fig 2–1d). Adverse laser effects are generally believed to be limited largely to the retina in this spectral region. The effect upon the retina may be a temporary reaction without residual pathologic changes, or it may be more severe with permanent pathologic changes resulting in a permanent scotoma. The mildest observable reaction may be simple reddening; but, as the retinal irradiance is increased, lesions may occur which progress in severity from edema to charring, with 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 the physical structure of the eye. 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 less than 520 nm may produce some photochemical retinal damage.

c. Ultraviolet radiation (180-400 nm) (fig 2–1, items b and c.) Actinic ultraviolet radiation, UV-B and UV-C (180-315 nm), can produce symptoms similar to those observed in arc welders. It may cause severe acute inflammation of the eye and conjunctiva. UV-B and UV-C radiation does not reach the retina. Near ultraviolet radiation (UV-A) is absorbed principally in the lens which causes the lens to fluoresce. Very high doses can cause corneal and lenticular opacities. Insignificant levels of UV-A reach the retina.

385–40, appendix B. Addressees will consist of HQDA (DASG-PSP) WASH DC 20310–2300, HQDA (DAPE-HRS), WASH DC 20310–0300, and Commander, AMC (AMCSF–P), 5001 Eisenhower Avenue, Alexandria, VA 22333–0001.

b. A representative of either the Occupational and Environmental Medicine Division (AUTOVON 584-3030) or the Laser Microwave Division (AUTOVON 584-3932), USAEHA, should be consulted immmediately upon suspicion or confirmation of an exposure incident. If an incident occurs during nonduty hours, call AUTOVON 584-4375.

Section III. PROTECTION STANDARDS

2–7. General. A complete listing of exposure limits for the maximum permissible exposure of the eye and skin specified in AR 40–46 are provided in appendix C. Exposure limits commonly required for the evaluation of lasers used in military applications are given in table 2–1.

CHAPTER 3

HAZARDS OF LASER APPLICATION

Section I. EVALUATION OF HAZARDS

3–1. General Procedure. Three aspects of a laser application influence the total hazard evaluation and thereby influence the application of control measures. These are the—

a. Laser device's capability of injuring personnel.

b. Environment in which the laser is used.

c. Personnel who may be exposed.

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 approximate controls for each classification. The use of the hazard classification method will in most cases preclude any requirement for laser measurements and greatly reduce the need for calculations. This standardized laser hazard classification scheme defines *aspect 1* as the potential hazard of the laser device. *Aspects 2* and *3* vary with each laser application and cannot be readily included in a general hazard classification scheme. The total hazard evaluation procedure must consider all three aspects, although in most cases only *aspect 1* influences the control measures that are applicable.

3–2. Laser and Laser System Hazard Classification Scheme. *a.* The four hazard classifications are defined by the laser output parameters and are specified in detail in appendix D. The general classification scheme with general hazard control concepts follows:

(1) Class 1 laser devices are those *not* capable of emitting hazardous laser radiation under any operating or viewing condition.

(2) Class 2 laser devices are continuous wave (CW) visible (400 to 700 nm) laser devices. Precautions are required to prevent continuous staring into the direct beam; momentary (>0.25 sec) exposure occurring in an unintentional viewing situation is not considered hazardous.

(3) Class 3b laser devices are potentially hazardous if the direct or specularly reflected beam is viewed by the unprotected eye, but do not (unless focused) cause hazardous diffuse reflections. Care is required to prevent intrabeam viewing and to control specular reflections. Class 3a lasers are normally not hazardous unless viewed with magnifying optics from within the beam.

(4) Class 4 lasers are those pulsed visible and near-infrared lasers capable of producing diffuse reflections, fire and skin hazards, or those lasers with an average output power of 500 milliwatts (mW) or greater. Safety precautions associated with Class 4 lasers generally consist of using door interlocks to prevent exposure to unauthorized or transient personnel entering the laser facility; the use of baffles to terminate the primary and secondary beams; and the wearing of protective eyewear and clothing by personnel.

b. This classification scheme is identical to that used in American National Standards Institute (ANSI) Standard ANSI-Z-136 and virtually identical to the Federal product performance standards in part 1040, title 21, Code of Federal Regulations (21 CFR 1040). This classification already appears on commercial laser products manufactured after July 1976 and should be used unless the laser is modified to significantly change its output power or energy, or unless the laser is enclosed.

3–3. Environment. Following the laser system hazard classification, environmental factors require consideration. Their importance in the total hazard evaluation depends upon the laser hazard classification. The decision to employ additional hazard controls not specifically required in paragraphs 3–2*a*(3) and (4) for Class 3 and Class 4 laser devices depends largely on environmental considerations. The probability of personnel exposure to hazardous laser radiation will be considered and is influenced by whether the laser is used indoors, like: in a machine shop, in a classroom, in a research laboratory, or a factory production line; or outdoors, like: on a range, in the atmosphere above occupied areas, or in a pipeline construction trench. Other environmental hazards (sec III) shall be considered. If exposure of unprotected personnel to the primary or specularly reflected beam is expected, calculations or measurements of either irradiance or radiant exposure of the primary or specularly reflected beam (or radiance of an extended source laser) at that specific location are required. These detailed procedures are discussed in appendix E.

a. Indoor laser operations. In general, only the laser device classification is considered in evaluating an indoor laser operation if the beam is enclosed or is operated in a controlled area. The following step-by-step procedure is recommended for evaluation of indoor Class 3 lasers when this is necessary (since there is a potential exposure of unprotected personnel with this particular class of laser devices).

tially hazardous laser radiation, the hazard evaluation is affected. Control measures could require appropriate modification.

(*b*) The type of personnel influences the total hazard evaluation (principally with the use of Class 3 lasers). Keep in mind that for laser rangefinders, designators, and some Class 3 lasers used in construction, the principal hazard control rests with the operator not to aim the laser at personnel or flat mirror-like surfaces.

(2) The following are considerations to be taken into account regarding personnel who may be exposed:

(*a*) Maturity and general level of training and experience of laser user(s) (e.g., trainees, experienced soldiers, scientists).

(*b*) Potentially hazardous laser radiation may be present and onlookers may not have knowledge of relevant safety precautions.

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

(*d*) Reliability of individuals to wear eye protection, if required.

(*e*) Laser exposure that may be intentional for the application.

(*f*) Number and location of individuals relative to the primary beam or reflections, and probability of accidental exposure.

Section II. HAZARD CONTROLS FOR LASER RADIATION

3–4. General. Remember that the hazard classification scheme given in paragraph 3–2 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 persons using the laser, and other environmental and personnel factors may play a role in determining the full extent of hazard control measures. Since such situations shall require informed judgments by responsible persons, major responsibility for such judgments shall be assigned to a qualified person, namely a laser safety officer. Only properly trained persons shall be designated laser safety officers or be placed in charge of Classes 3 and 4 laser installations or operations. Complete enclosure of a laser beam (an enclosed laser) shall be used when feasible. A closed installation provides the next most desirable hazard control measure. Following are details relating to a safe laser operation in an—

a. Outdoor environment where administrative controls often provide the only reasonable approach.

b. Indoor environment where engineering controls should play the greatest role.

3–5. Outdoor Laser Installations. *a. Class 2 laser devices.* The beam will be terminated where readily feasible at the end of the useful beam path, and the laser shall not be directed at personnel who do not expect to be illuminated.

b. Class 3 and 4 lasers.

(1) Unprotected personnel shall be excluded from the beam path at all points where the beam irradiance or radiant exposure exceed the appropriate exposure limit. This shall be accomplished by the use of physical barriers, administrative controls, and by limiting the beam traverse.

(2) The tracking of nontarget vehicular traffic or aircraft shall be prohibited.

(3) The target area shall be cleared of all flat specular surfaces capable of producing reflections that are potentially hazardous, or eye protection shall be required for all personnel within the hazardous area.

(4) Sections III and IV provide detailed guidance applicable to range control of laser rangefinders and designators.

c. Class 4 laser. Operation of Class 4 laser devices while it is raining or snowing, or when there is dust or fog in the air should be avoided unless laser protective eyewear is worn by personnel within the immediate vicinity of the beam (e.g., within 2–3 ft of the beam path).

3–6. Indoor Laser Installations. *a. Class 4 laser installations—specific precautions.* Pulsed Class 4 visible and IR-A lasers are hazardous to the eye from direct beam viewing, and from specular (and sometimes diffuse) reflections of the laser beam. Class 4 ultraviolet, infrared, and CW visible lasers present a potential fire and skin hazard. Safety precautions associated with high-risk lasers generally consist of using door interlocks to prevent exposure to unauthorized or transient personnel entering the controlled facility; the use of baffles to terminate the primary and secondary beams; and the wearing of protective eyewear or clothing by personnel within the interlocked facility.

(1) Safety interlocks at the entrance of the laser facility shall be so constructed that unauthorized or transient personnel shall be denied access to the facility while the laser is capabe of emitting laser radiation in excess of Class 4 levels.

(2) Laser electronic-firing systems for pulsed lasers shall be so designed that accidental pulsing of a

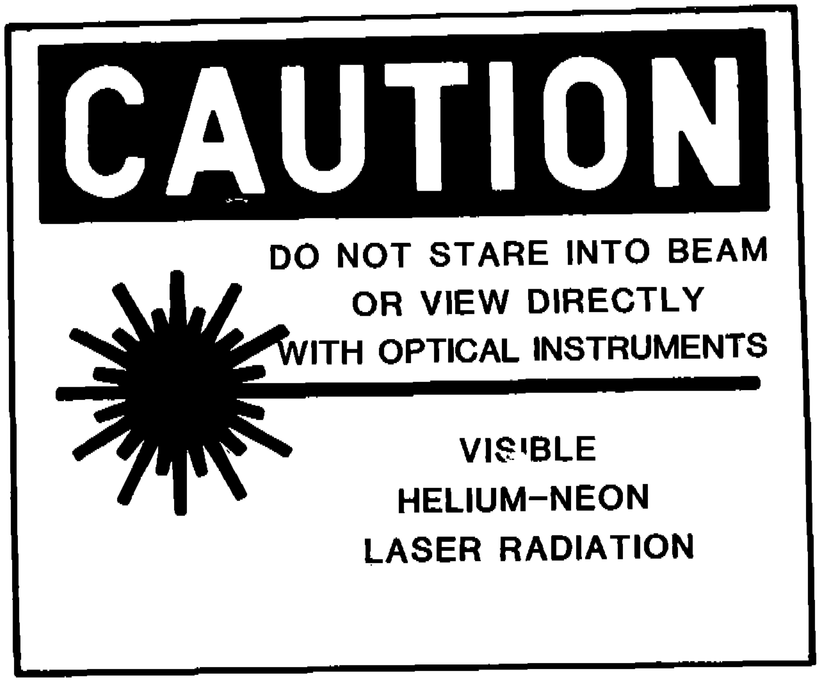


Figure 3–4. Class 3a laser warning label.

Figure 3–5. Class 3b or 4 laser warning label.

Section III. RECOGNITION OF ASSOCIATED HAZARDS

3–8. Atmospheric Contamination. Adequate ventilation or enclosures shall be employed to control—

a. Vaporized target material from high-energy cutting, drilling, and welding operations. Materials involved may include carbon monoxide, carbon dioxide, ozone, lead, mercury, and other metals.

b. Gases from flowing gas lasers or byproducts of laser reactions such as bromine, chlorine, hydrogen cyanide, and many others. Ozone created by laser-produced plasma.

c. Gases or vapors from cryogenic coolants.

d. Vaporized biological target materials from high-energy lasers used in biological or medical applications.

3–9. Ultraviolet Radiation. Either direct or reflected ultraviolet (UV) radiation from flash lamps and CW laser discharge tubes should be shielded. UV radiation is generally only of concern when quartz tubing is used. Personnel shall not be exposed to levels of UV radiation in excess of exposure limits given in AR 40–46.

3–10. Visible and Near-infrared Radiation. High-intensity optical pumping systems may present a potential retinal hazard and should be shielded.

3–11. Electrical Hazards. The potential for electrical shock is present in most laser systems. Pulsed lasers utilize capacitor banks for energy storage and CW lasers generally have high voltage direct current or radio frequency electrical power supplies. Solid-conductor grounding rods (connected first to a reliable ground) shall be utilized to discharge potentially live circuit points prior to maintenance. Maintenance personnel shall familiarize themselves with the safety procedures provided in the maintenance manual for the device.

3–12. Cryogenic Coolants. Cryogenic coolants may cause skin or eye injury if improperly used (e.g., liquid nitrogen, liquid helium, and liquid hydrogen).

3–13. Other Hazards. The potential for explosions at capacitor banks or optical pump systems exists during the operation of some high-power lasers or laser systems. The possibility of flying particles from target areas in laser cutting, drilling, and welding operations may exist. Explosive reactions of chemical laser reactants or other gases used within certain laser laboratories is of concern in some cases.

3–14. X-rays. X-rays may be generated from high-voltage (over 15 kilovolts (kV)) power supply tubes. Adequate shielding shall be employed.

Section IV. SIMPLIFIED RANGE CONTROL MEASURES FOR TYPICAL OPERATIONS OF LASER RANGEFINDERS AND DESIGNATORS

3–15. Limitations. The guidance provided in this section deals with range operations in which the laser rangefinder or designator is aircraft- or vehicle-mounted, tripod-mounted or hand-held, and has a hazardous range of at least 1 kilometer (km). These guidelines should not be applied to laser systems other than those having a beam divergence of 1 degree (17 milliradians) or less.

3–16. Background. *a.* The laser system, except for its inability to penetrate targets, can be treated to some extent like a direct-fire, line-of-sight weapon, such as a rifle or machine gun. Thus, the hazard control precautions (AR 385–63) 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. Special control measures for laser use are discussed below.

b. The hazard from these types of laser devices 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 damage with permanent impairment of vision can result to unprotected personnel exposed to the laser beam. The hazard of exposure to the skin is small compared to exposure to the eye; however, personnel should avoid direct exposure to the unprotected skin within a Distance t (see table 3–1) of the laser. 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 (see fig 3–8). Calculated NOHDs often extend even beyond 10 km, and the use of optical viewing instruments within the beam could extend the NOHD considerably. For this reason, and because of atmospheric effects upon the beam, the designation of a single "safe" range for firing range safety purposes is not feasible for most testing and training purposes. An official NOHD is established by the USAEHA for specialized use by installation range control officers.

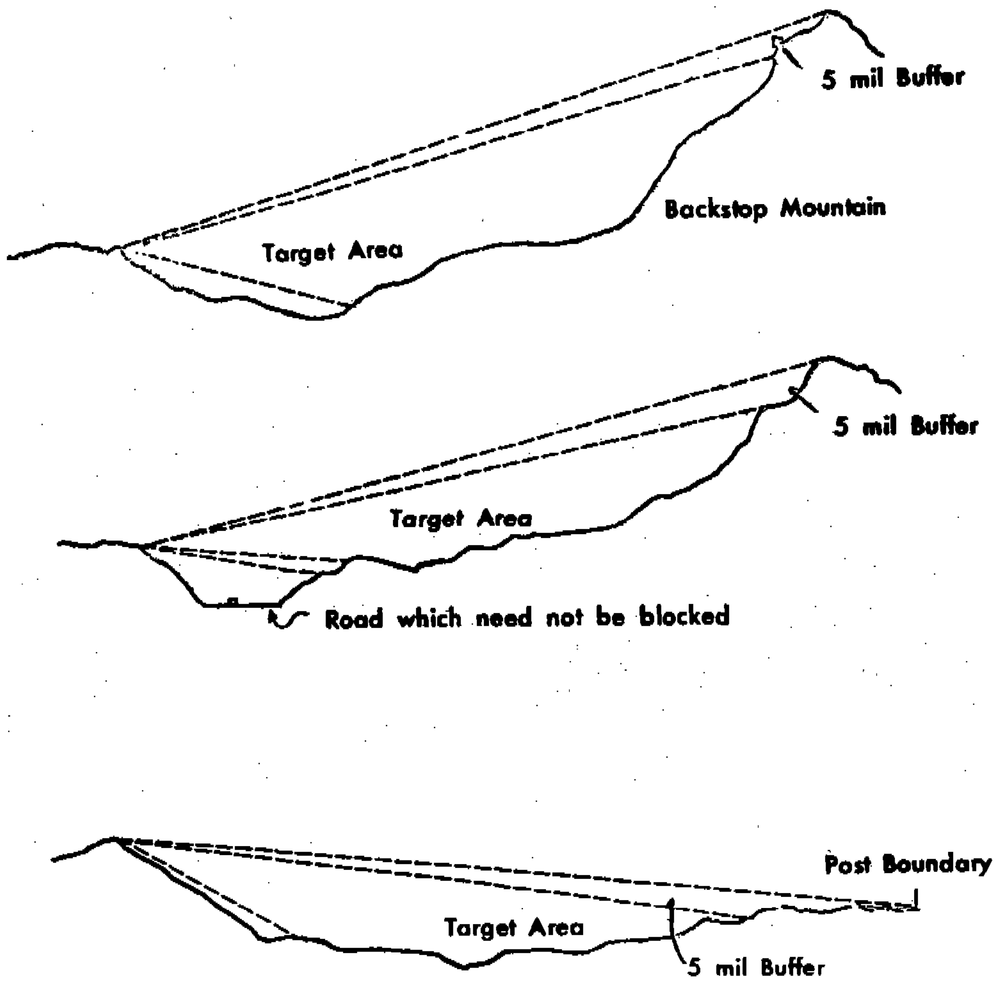


Figure 3–8. Laser range terrain profiles with backstops.

(3) Safety standards for operational control procedures.

(4) Protective equipment.

(5) Preparation of range areas for laser use (e.g., cover, remove, or avoid flat specular surfaces).

(6) Laser indoctrination should be provided to students during relevant advanced individual training (AIT), and to officers during basic courses, simultaneously with the basic weapon systems instruction. The classroom instructors should be knowledgeable in operator and crew aspects of laser safety. Reference publications on subject lasers should be readily available. The instruction presented should be at the user level (complex scientific data or terminology should be avoided). Training films, if available, should be included in the instruction program. Hazard data on lasers incorporated into TMs and FMs on the related weapon system or on the laser subsystem should be stressed. Information as to the appropriate channels for obtaining professional safety and medical assistance should be addressed during the indoctrination period.

3–18. Range Control Procedures. The underlying concept of range safety is to prevent intrabeam viewing by unprotected personnel. This is accomplished by locating target areas where no lines-of-sight exist between lasers and uncontrolled, potentially occupied areas, and by removing flat specular surfaces from targets. Recommended target areas are those without specular (mirror-like) surfaces. A flat specular surface is one in which you can see a relatively undistorted image. Examples of specular surfaces are vehicle windows, vision blocks, searchlight cover glass, plastic sheets, or mirrors. Glossy foliage, raindrops, and other natural objects are not hazardous targets. If target areas have no flat specular surfaces, range control measures can be limited to the control of the direct beam path between the laser and the backstop.

3–19. Range Boundaries. *a. Nominal ocular hazard distance.* The NOHD for direct intrabeam viewing is the distance beyond which an unprotected individual may stand in the beam and be exposed repeatedly

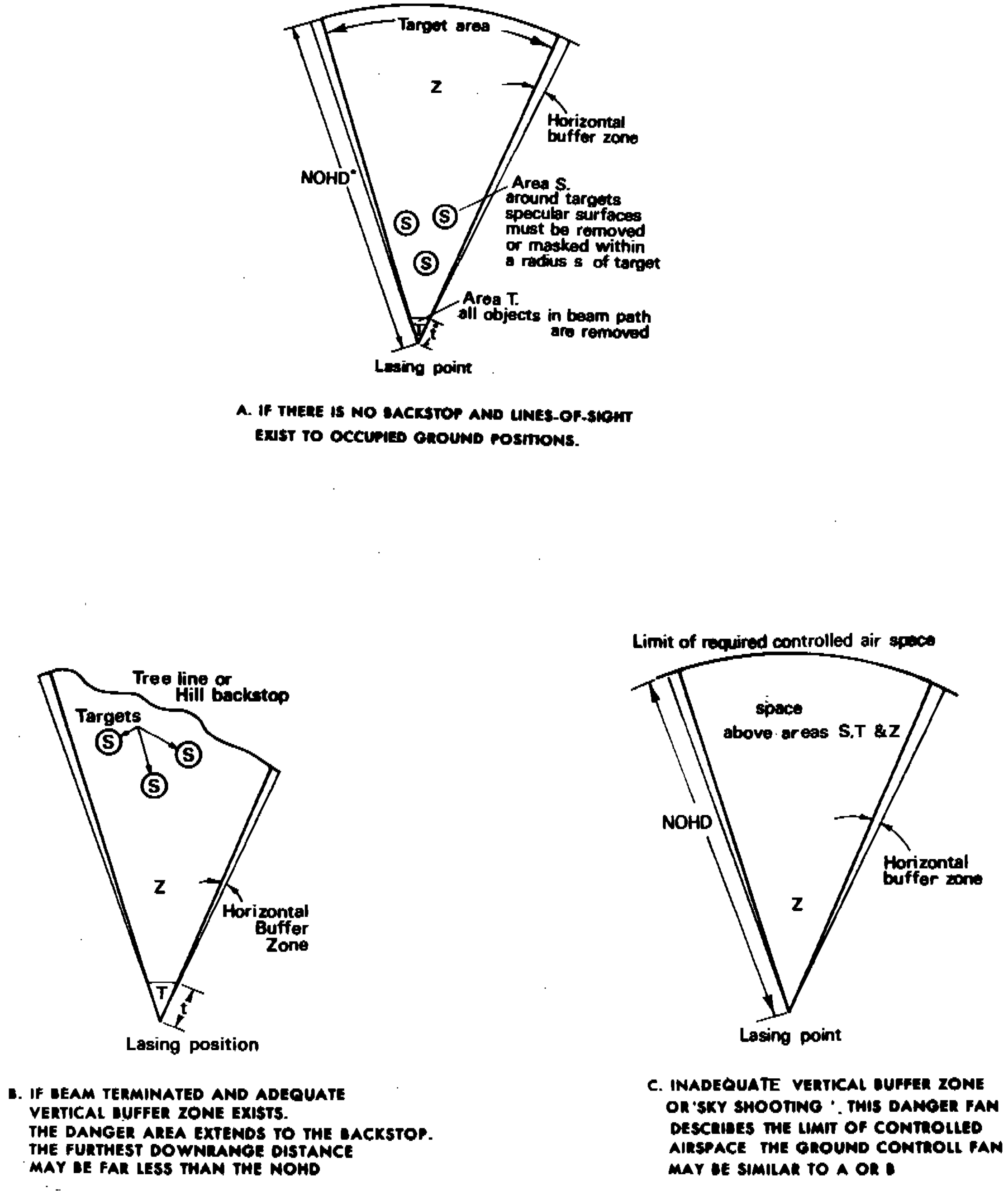


Figure 3–9. Laser safety danger zones.

ground. Signs should also be according to AR 385–30.

3–22. Approved Targets. The laser operator shall—

a. Only fire at designated targets that are diffuse reflectors.

b. Never fire at specular surfaces such as glass, mirrors, windows, flat chrome-plated surfaces, etc. This constraint can be met by removing, covering, or painting specular surfaces on vehicles with lusterless paint.

3–23. Eye Protection. Those within the LSDZ for each device, such as moving target operators, shall wear laser protective eyewear with *curved* protective lenses during laser firing (see para F–2*f*). Such eyewear must be approved for the wavelength of the laser device being fired (such as AN/VVG–1, etc.). A laser filter designed for protection against one wavelength of laser may not protect against harm from another. See table 3–2 for the wavelength and optical density required for the currently fielded devices. If more than one type of device is used, protective mea-

h. The installation range control officer and local air traffic controllers shall assure that adequate danger zones are established and that strict control of traffic is maintained as necessary. Normally a range control office(r) 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 their engaging in any mission within the danger area in which lasing will take place. The briefing should include the geography of the area, access and exit routes, limits of flight pattern, radio frequencies to be employed, and applicable local procedures. Whenever practicable, each pilot assigned to a training mission shall make a dry run prior to the mission to become acquainted with the prescribed course and the test area.

i. Laser operations shall not be initiated unless appropriate buffer zones (table 3–1) exist on all sides of the target within the government controlled property area.

3–28. Laser Safety Output Attenuators. Optical glass filters have been developed to greatly reduce the output energy of some fielded lasers (e.g., the M60A3 tank LRF, the AN/GVS–5 LRF, and the AN/TVQ–2). These filters reduce the NOHD or completely eliminate a hazardous laser output for training purposes. Use of some filters make it possible for lasers to be used during two-sided tactical exercises. Revised safety procedures applicable to filter use are given in the appropriate TMs (see table 3–2).

3–29. Hangar, Garage, and Maintenance Shop Procedures. *a.* All testing performed in shop areas will be strictly controlled with barriers and signs.

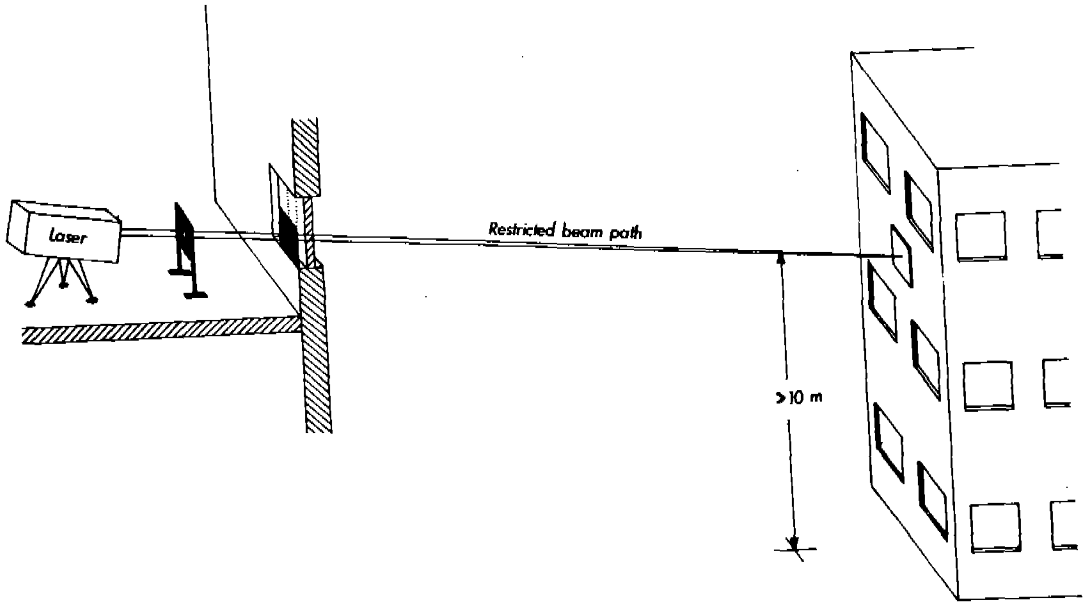
b. Firing of the laser in shop areas should be into a light-tight box expressly designed to contain all of the laser output, where feasible.

c. The maintenance officer shall insure that the number of operating personnel on the site for testing does not exceed that necessary to accomplish the task safely and efficiently. Transient personnel are restricted to those having an official interest in the test and shall be cleared by the maintenance officer.

d. Check tests requiring operation of a laser over an extended distance (i.e., 100 m to 1000 m)—

(1) Should be conducted in occupied areas only under strict controls.

(2) Insure that the beam can only travel along a tightly controlled path defined by a beam aperture located at 1 m and 10 m from the laser (fig 3–10).



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

Figure 3–10. Maintenance test range.

CHAPTER 4
PERSONAL PROTECTIVE EQUIPMENT

4–1. Eye Protection. *a.* Personnel whose occupation or assignment require exposure to laser beams should be furnished suitable laser safety goggles. The goggles shall protect for the specific wavelength(s) of the laser and have an optical density adequate for the energy involved.

b. Table 4–1 lists the maximum power, energy, irradiance, or radiant exposure for which adequate protection is afforded by filters of optical densities from 1 through 7.

c. Eye protection should have curved lenses to reduce specular reflection hazards.

4–2. Skin Protection. Needless exposure of the skin of personnel should be avoided for Classes 3 and 4 lasers. When the hands or other parts of the body must be exposed to potentially hazardous levels, protective coverings, gloves, or shields shall be used. The face should be turned away from the target area. Laser welding and cutting facilities should have sufficient shielding surrounding the article being welded to prevent viewing the operation by persons other than the welder.

4–3. Low Temperature Protection. Impervious, quick removal gloves, face shields, and safety glasses should be provided as protection for personnel who handle the extremely low temperature coolants that may be used in some high-powered lasers.

CHAPTER 5
ADMINISTRATION

5–1. Accident Reporting. Procedures now in effect for reporting suspected overexposures from nonionizing radiation are given in AR 40–400 and AR 385–40. AR 40–400 requires that when an individual is treated on an inpatient or outpatient basis for a suspected overexposure to nonionizing radiation that a MED 16 form be submitted to HQDA (DASG-PSP). Per AR 385–40, nonionizing radiation accidents shall be reported within 72 hours to HQDA (DASG-PSP), HQDA (DAPE-HRS), and AMC (AMCSF-P/AMCSG-R). Any necessary investigation shall be directed by HQDA (DASG-PSP).

5–2. Biological Data. The Division of Ocular Hazards, LAIR, conducts research and development to obtain data on the biomedical effects of laser radiation. Biological research data required for the safety evaluation of new types of lasers is available to development agencies upon written request to: Chief, Division of Ocular Hazards, Letterman Army Institute of Research, Presidio of San Francisco, CA 94129–6700.

5–3. Technical Assistance. The services of USAEHA are available upon written request to Commander, US Army Environmental Hygiene Agency, ATTN: HSHB-RL, Aberdeen Proving Ground, MD 21010–5422, with a copy furnished to Commander, US Army Health Services Command, ATTN: HSCL-P, Fort Sam Houston, TX 78234–6000.

APPENDIX A
REFERENCES

Section I. REQUIRED PUBLICATIONS

AR 10–5	Department of the Army.
AR 40–5	Preventive Medicine.
AR 40–46	Control of Health Hazards from Lasers and Other High Intensity Optical Sources.
AR 40–400	Patient Administration.
AR 385–30	Safety Color Code Markings and Signs.
AR 385–9	Safety Requirements for Military Lasers.
AR 385–40	Accident Reporting and Records.
AR 385–63	Policies and Procedures for Firing Ammunition for Training, Target Practices, and Combat.
TB MED 506	Occupational Vision.

Section II. RELATED PUBLICATIONS*

FM 21–11 (Test)	First Aid for Soldiers
TM 9–1260–477–12	Operator's and Organizational Maintenance Manual for Electro-Optical Target Designator Set, AN/TVQ–2 (G/VLLD) (NSN 1260–01–046–2843) and (G/VLLD M113A1 Vehicle Adapter (NSN 2590–01–046–2832)
TM 9–1260–479–12	Operator's and Organizational Maintenance Manual for Laser Target Designator, AN/PAQ–1 (LTD)
TM 9–2350–230–10	Operator's Manual (Crew) for Armored Reconnaissance/Airborne Assault Vehicle, Full-Tracked, 152–MM Gun/Launcher M551 (NSN 2350–00–873–5408) and M551A1 (NSN 2350–00–140–5151)
TM 9–2350–232–10	Operator's Manual: Tank, Combat, Full-Tracked: 152–MM Gun/Launcher, M60A2 W/E (NSN 2350–00–930–3590)
TM 9–2350–253–10	Operator's Manual for Tank, Combat, Full-Tracked, 105–MM Gun, M60A3 (NSN 2350–00–148–6548) and TTS (Tank Thermal Sight) (NSN 2350–01–061–2306)
TM 9–2350–255–20–1–1	Organizational Maintenance Manual Scheduled Maintenance for Tank, Combat, Full-Tracked: 105–MM Gun, M1 (NSN 2350–01–061–2445), GENERAL ABRAMS, Hull
TM 11–5860–201–10	Operator's Manual: Laser Infrared Observation Set, AN/GVS–5 (NSN 5860–01–062–3543)
TM 55–1520–236–10	Operator's Manual, Army Model AH–1S (PROD), AH–1S (ECAS), and AH–1S (Modernized Cobra) Helicopters

A Guide for Control of Laser Hazards. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio (1981).

Laser Safety Guide. Laser Institute of America, Cincinnati, Ohio (1976).

**A related publication is merely a source of additional information. The user does not have to read it to understand this bulletin.*

APPENDIX B
INTRODUCTION TO LASERS

B–1. General Information. *a.* Lasers are finding ever increasing military applications—principally for target acquisition, fire control, and training. These lasers are termed rangefinders, target designators, and direct-fire simulators. Lasers are also being used in communications, precision distance measurements, guidance systems, metal working, photography, holography, and medicine.

b. Laser radiation should not be confused with ionizing radiation (X-rays and gamma rays) even though laser beams with high irradiances have been known to produce ionization.

c. The word *laser* will be applied to devices using light amplification by stimulated emission of radiation and usually operating with an output wavelength of approximately 180 nm (0.18 μm) to 1000 μm (1 mm). Most lasers operate in one of the following modes—

(1) Continuous wave (CW).
(2) Normal pulse.
(3) Q-switched pulse.
(4) Mode-locked pulse.
(5) Repetitively pulsed.

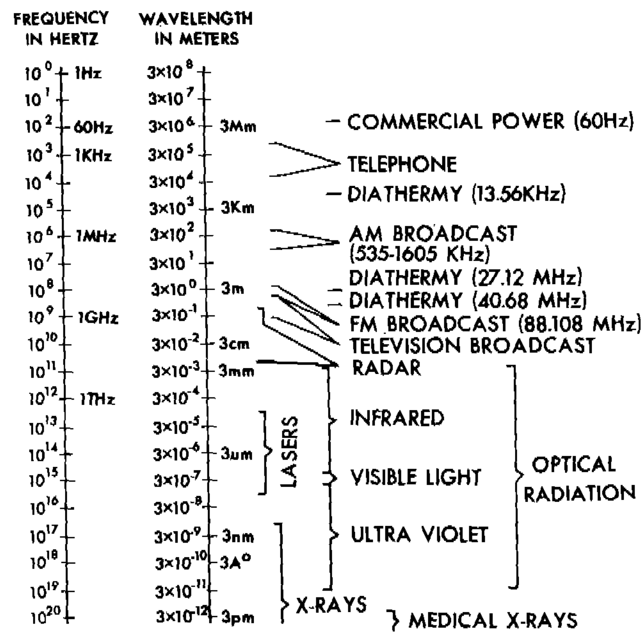


Figure B–1. The electromagnetic spectrum.

B–2. The Nature of Light. 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 which propagates at approximately 3×10^8 meters per second. Albert Einstein later predicted that the velocity of light in a vacuum was constant throughout the universe and was the ultimate speed at which energy may be transmitted. Quantum mechanics describe the smallest indivisible quantity of radiant energy as one photon. The amount of energy (Q_q), represented by one photon, is determined by the frequency ν, and Planck's constant, h.

$$Q_q = h\nu$$

The frequency, ν, and wavelength, γ, of light are related by the velocity of light, c, so that knowing one, the other may be determined by use of the relationship.

$$c = \nu\lambda$$

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

B–3. Production of Light. *a.* Electromagnetic radiation is emitted whenever a charged particle (e.g., an electron) gives up energy into an electric field. This happens every time an electron drops from a higher energy state to a lower energy state in an atom or ion (fig B–2).

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 photons of precisely the right energy. The stimulated emissions occur with exactly the same wavelength, phase, and direction as the photons that stimulated the emissions.

c. Electrons must be raised to higher energy levels before they can make the transitions to lower energy levels and radiate photons. There are many ways in which electrons can be raised to high energy levels or become "excited." By—

(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, a molecule can also have energy levels arising

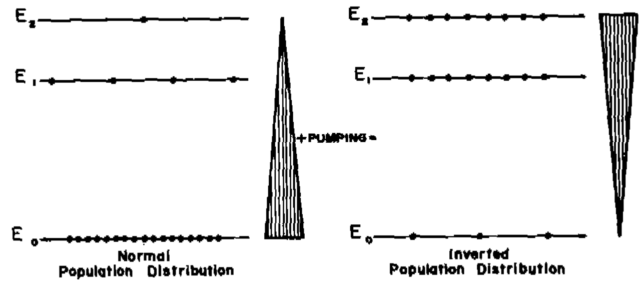
B–6. Pumping System. To raise atoms or molecules to a higher energy level, lasers employ pumping systems (fig B–4). These systems pump energy intc the laser material, increasing the number of atoms or molecules in the metastable energy state. When the number of atoms or molecules in the metastable energy state exceeds those in the lower level, a *population inversion* exists and laser action is possible. Several different pumping systems are available. These are—

a. Optical pumping which uses a strong source of light, such as a xenon flashtube or another laser (e.g., an argon laser).

b. Electron collision pumping which 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 (e.g., Helium-Neon lasers).

c. Chemical pumping which is based on energy released in the making and breaking of chemical bonds (e.g., Hydrogen-Fluoride lasers).

B–7. Optical Cavity. A resonant optical cavity is formed by placing a mirror at each end of the laser material so that a beam of light may be reflected from one mirror to the other, passing back and forth through the laser material (fig B–5). Lasers are constructed in this way so that the beam passes through the material many times and is amplified each time. One of the mirrors is only partially reflecting and permits part of the beam to be transmitted out of the cavity.

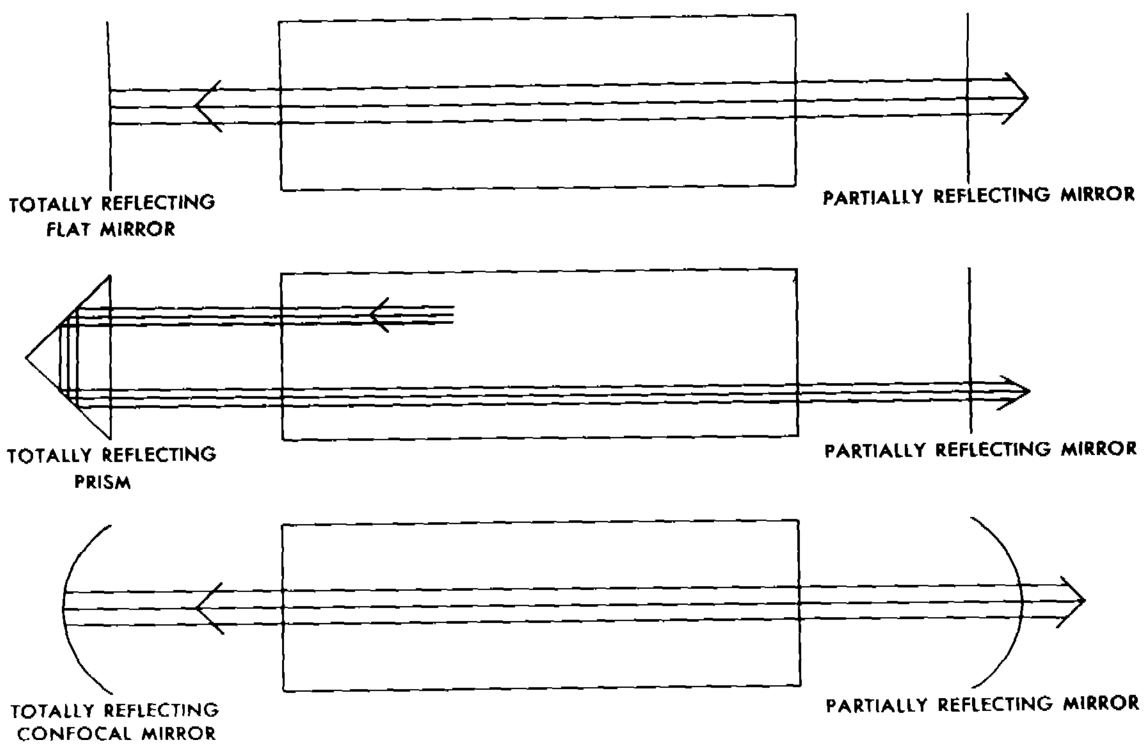


This inversion is produced by pumping electrons from a lower energy state to a higher energy state so that the higher state has more electrons (larger population) than the lower state.

Figure B–4. Population inversion.

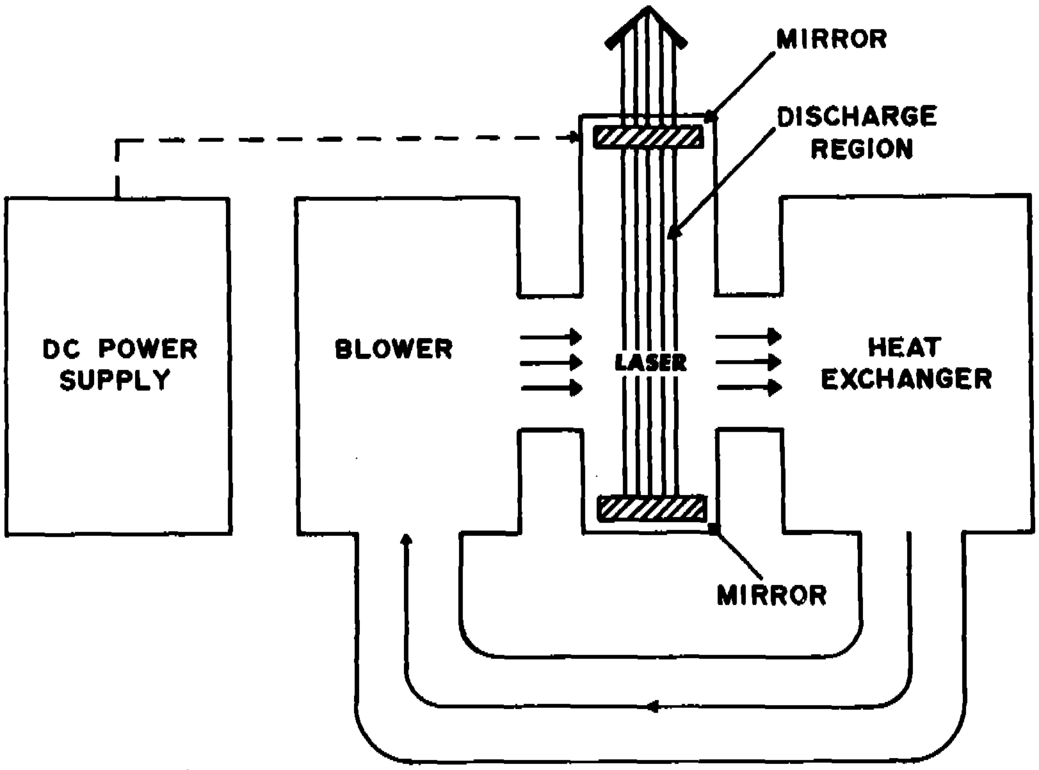
B–8. Laser Operation. *a.* Energy is supplied to the laser material by the pumping system. This energy may be stored in the form of electrons trapped in metastable energy levels. Pumping must produce a population inversion before laser action can take place.

b. A population inversion exists for this type of laser when a higher energy level has more electrons



Simple flat mirror system (top).
Rotating prism Q-switch system (middle).
Confocal mirror system (bottom).

Figure B–5. Three typical optical cavities.



This is representative of a larger type of flowing-gas laser. A still larger type of gas laser (not shown) employs a combustion chamber and supersonic nozzles for population inversion and is known as a gas dynamic laser (GDL).

Figure B–8. Schematic of CO_2 gas transport laser (GTL).

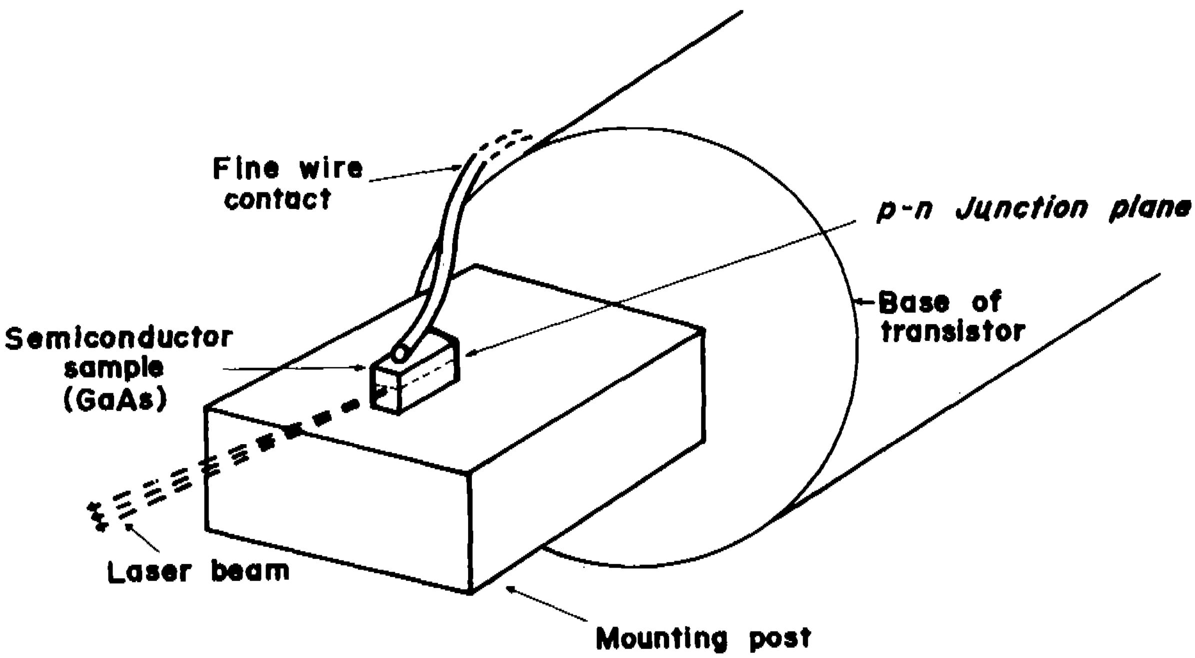


Figure B–9. Schematic of gallium-arsenide laser with direct-current (electron collision) pumping (representative of semiconductor or injection lasers).

irradiance or radiant exposure is 1/2, 1/e, 1/e², or 1/10

Figure B–12. Irradiance or radiant exposure at various points in the beam cross-section.

APPENDIX C
LASER EXPOSURE LIMITS

C–1. General. These exposure limits (ELs) are for maximum permissible exposure to laser radiation under conditions to which nearly all personnel may be exposed without adverse effects. The 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 C–1, C–2, and C–3 provide the complete list of laser ELs. Figures C–1 through C–6 provide graphs of exposure limits that may be difficult to calculate.

Table C–1. Exposure limits for direct ocular exposures (intrabeam viewing) from a laser beam.

Spectral region	Wavelength (nm)	Exposure time, † (seconds)	Exposure limit	Defining aperature (mm)	
UV-C	200-302	10^{-9} - $3x10^{4}$	3 $mJ{\cdot}cm^{-2}$	1	
UV-B	303	10^{-9} - $3x10^{4}$	4 $mJ{\cdot}cm^{-2}$	1	
	304	10^{-9} - $3x10^{4}$	6 $mJ{\cdot}cm^{-2}$	1	
	305	10^{-9} - $3x10^{4}$	10 $mJ{\cdot}cm^{-2}$	1	
	306	10^{-9} - $3x10^{4}$	16 $mJ{\cdot}cm^{-2}$	1	
	307	10^{-9} - $3x10^{4}$	25 $mJ{\cdot}cm^{-2}$	1	
	308	10^{-9} - $3x10^{4}$	40 $mJ{\cdot}cm^{-2}$	1	or $0.56t^{1/4}$ $J{\cdot}cm^{-2}$
	309	10^{-9} - $3x10^{4}$	63 $mJ{\cdot}cm^{-2}$	1	
	310	10^{-9} - $3x10^{4}$	100 $mJ{\cdot}cm^{-2}$	1	
	311	10^{-9} - $3x10^{4}$	160 $mJ{\cdot}cm^{-2}$	1	
	312	10^{-9} - $3x10^{4}$	250 $mJ{\cdot}cm^{-2}$	1	
	313	10^{-9} - $3x10^{4}$	400 $mJ{\cdot}cm^{-2}$	1	
	314	10^{-9} - $3x10^{4}$	630 $mJ{\cdot}cm^{-2}$	1	
UV-A	315-400‡	10^{-9} - 10	0.56 $t^{1/4}$ $J{\cdot}cm^{-2}$	1	
	315-400	10 - 10^{3}	1.0 $J{\cdot}cm^{-2}$	1	
	315-400	10^{3} - $3x10^{4}$	1.0 $mW{\cdot}cm^{-2}$	1	

(Table C–1 continued on page C–2)

Table C–2. Exposure Limits for Viewing a Diffuse Reflection of a Laser Beam or an Extended Source Laser.

Spectral region	Wavelength (nm)	Exposure time, t (seconds)	Exposure limit
Light	400-700	10^{-9} - 10	$10\ t^{1/3}\ J{\cdot}cm^{-2}{\cdot}sr^{-1}$
	400-550	10 - 10^4	$21\ J{\cdot}cm^{-2}{\cdot}sr^{-1}$
	550-700	10 - T_1	$3.83\ t^{3/4}\ J{\cdot}cm^{-2}{\cdot}sr^{-1}$
	550-700	T_1 - 10^4	$21\ C_B\ J{\cdot}cm^{-2}{\cdot}sr^{-1}$
	400-700	10^4 - $3x10^4$	$2.1\ C_B\ mW{\cdot}cm^{-2}{\cdot}sr^{-1}$
Near infrared	700-1400	10^{-9} - 10	$10\ C_A\ t^{1/3}\ J{\cdot}cm^{-2}{\cdot}sr^{-1}$
	700-1400	10 - 10^3	$3.83\ C_A\ t^{3/4}\ J{\cdot}cm^{-2}{\cdot}sr^{-1}$
	700-1400	10^3 - $3x10^4$	$0.64\ C_A\ W{\cdot}cm^{-2}{\cdot}sr^{-1}$

Notes:

C_A, C_B, and T_1 are the same as in footnote to table C-1.

Table C–3. Exposure Limits for Skin Exposure From a Laser Beam.

Spectral region	Wavelength	Exposure time, t (seconds)	Exposure limit
UV	200 to 400 nm	10^{-9} - $3x10^4$	Same as table C-1
Light & infrared A	400 to 1400 nm	10^{-9} - 10^{-7}	$2\ C_A \times 10^{-2}\ J{\cdot}cm^{-2}$
do	do	10^{-7} - 10	$1.1\ C_A\ t^{1/4}\ J{\cdot}cm^{-2}$
do	do	10 - $3x10^4$	$0.2\ C_A\ W{\cdot}cm^{-2}$
Infrared B & C	1.4 μm to 1 mm	10^{-9} - $3x10^4$	Same as table C-1*

Note:

To aid in the determination of exposure limit for exposure durations requiring calculations of fractional powers, figure C-6a may be used. The limiting aperature for all of these ELs is 1 mm for wavelengths less than 0.1 mm. The limiting aperature for wavelengths greater than 0.1 mm is 11 mm.

* Whole-body exposure should be limited to 10 $mW{\cdot}cm^{-2}$. The above limits refer to a laser beam having a cross-sectional area less than 100 cm^2.

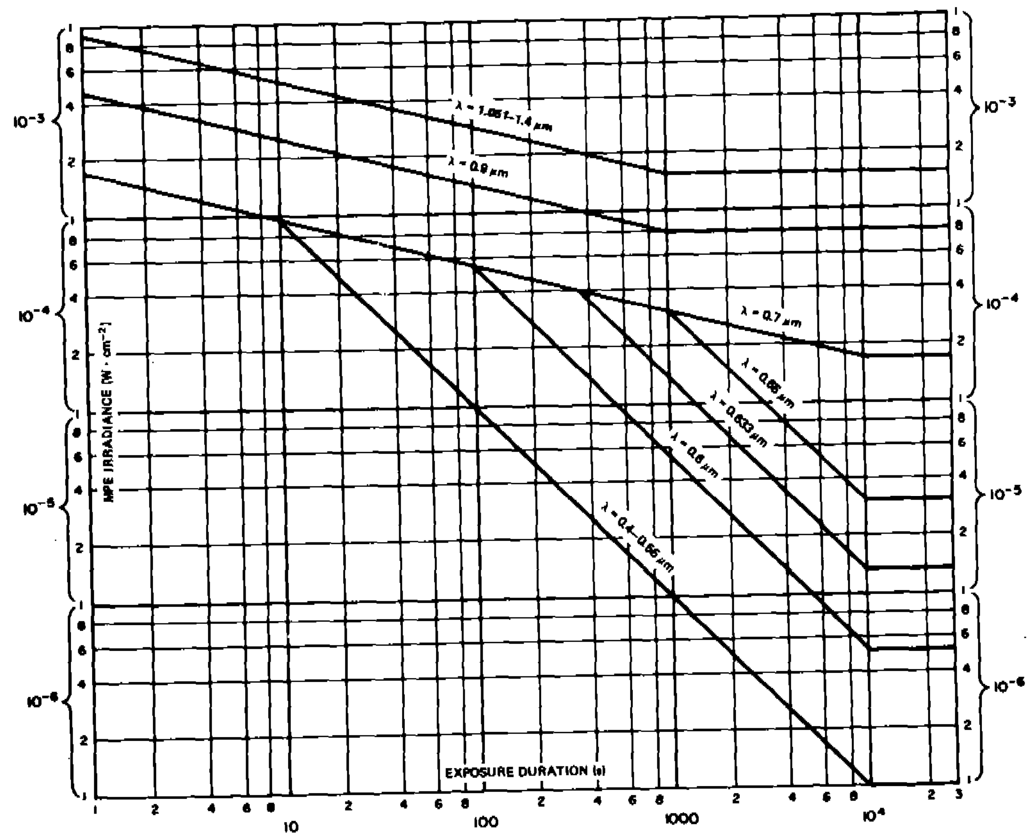


Figure C–1b. Exposure limit for intrabeam viewing of CW visible (400–700 nm) and IR-A (750, 900, and 1060–1400 nm) laser radiation.

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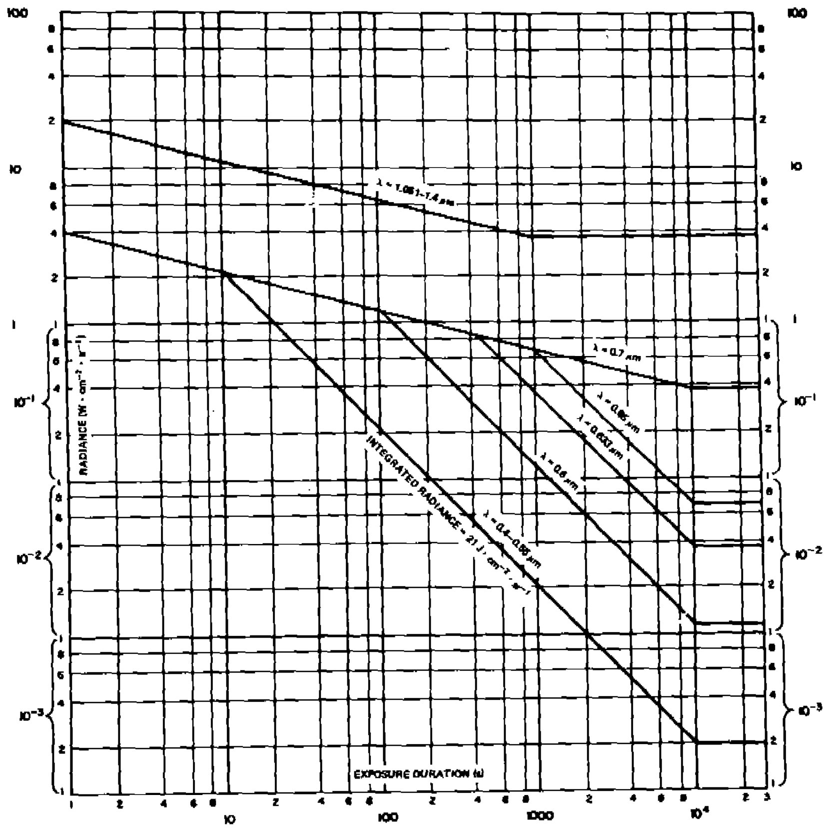

Figure C–2b. Exposure limit for extended sources or diffuse reflections of CW visible (400–700 nm) and IR-A (850, 900, and 1060–1400 nm) laser radiation.

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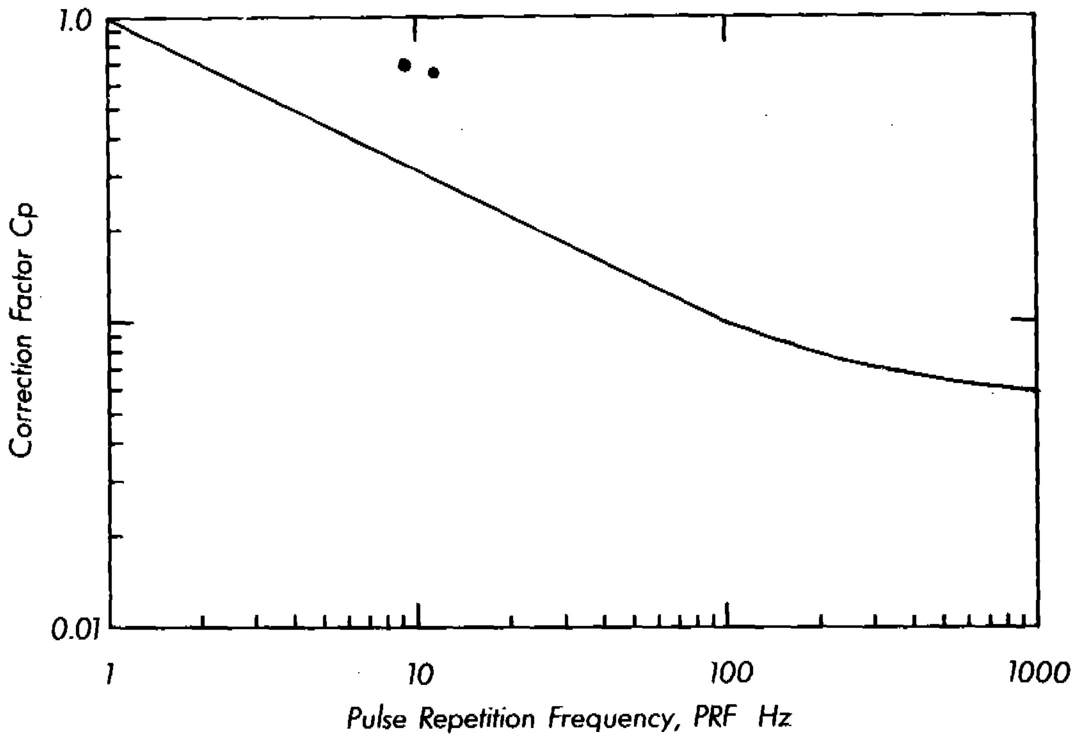
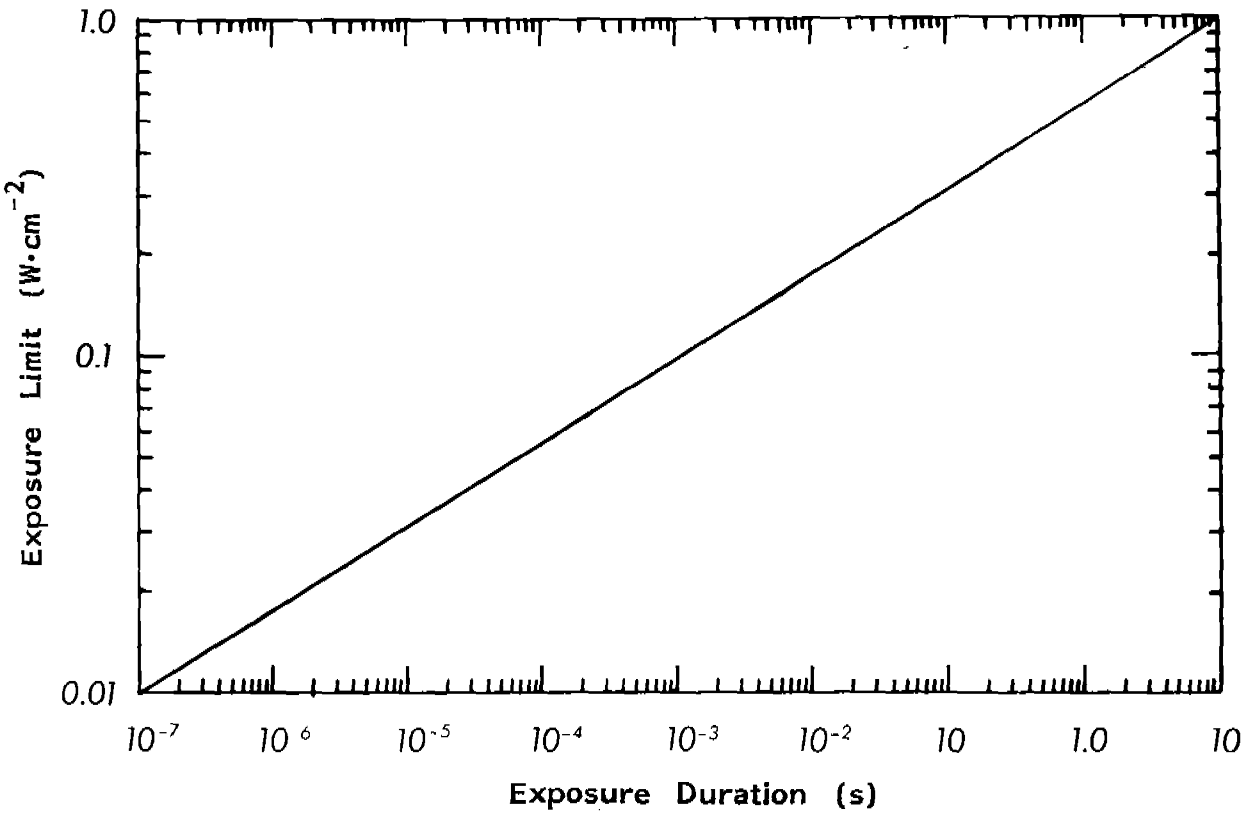


The exposure limit for a single pulse of a pulse train is multiplied by the above correction factor. C_p for PRF greater than 1000 Hz is 0.06.

Figure C–5. Correction factor C_p for repetitively pulsed lasers having pulse durations less than 10^{-5} second.



Exposure limits for skin exposure (400–1400 nm) are twice these values.

Figure C–6a. Exposure limit for pulsed laser exposure of skin and eyes for far-infrared radiation (wavelengths greater than 1400 nm).

APPENDIX D
LASER HAZARD CLASSIFICATION

D–1. General. Classification of most all lasers requires the following radiometric parameters:

a. Wavelength(s) or wavelength range.

b. For CW or repetitively pulsed lasers: average power output and limiting exposure duration inherent to the design of the laser or laser system, T_{max}.

c. For pulsed lasers: Total energy/pulse (or peak power), pulse duration, PRF, and emergent beam radiant exposure.

D–2. Extended Source Lasers. Classification of extended source lasers or laser systems (e.g., some injection laser diode arrays, and those lasers having a permanent diffuser within the output optics) require the laser source radiance or integrated radiance and the maximum viewing angular subtense. These are in addition to the parameters listed in table D–1.

D–3. Accessible Emission Limit (AEL) for Class 1. In a *worst-case* analysis of a laser's potential for producing injury, consider not only the laser output irradiance or radiant exposure, but also whether a hazard would exist if the total laser output were concentrated within the defining aperture for the applicable exposure limit. For instance, the unfocused beam of a far-infrared CW laser would not normally be hazardous if the beam irradiance were less than 0.1 $W{\cdot}cm^{-2}$; however, if the output power were 100 W and the beam were focused at some location to a 1-mm spot, a serious hazard could exist. This laser shall be evaluated in two different ways depending upon whether or not the laser itself is considered an *extended source* (an unusual case):

a. For most lasers, the AEL for Class 1 is the product of:

(1) The intrabeam exposure limit for the eye (table C–1) for the limiting exposure duration T_{max}, and

(2) The circular area of the defining aperture for the exposure limit (table C–1), in cm^2.

b. For extended-source lasers (such as laser arrays, laser diodes, and diffused-output lasers) that emit in the spectral range of 0.4 to 1.4 μm, the AEL Class 1 is determined by that power or energy output so that the source radiance does not exceed the exposure limit (table C–2) if the source were viewed at the minimum viewing distance. Theoretically, a perfect optical viewing system has an entrance aperture of 8 cm which collects the entire laser beam output and which has a 7-mm exit pupil. If this definition is difficult to apply, the definition in *a* above may be applied and will result in a conservative AEL for Class 1.

D–4. Classification of Multiwavelength Lasers. The classification of laser devices that can potentially emit at numerous wavelengths shall be based on the most hazardous possible operation.

D–5. Laser Device Hazard Classification Definitions. *a. Class 1.* Any laser device that cannot emit laser radiation levels in excess of the AEL for the maximum possible duration inherent to the design of the laser or laser system. The exemption from hazard controls strictly applies to emitted laser radiation hazards and not to other potential hazards.

b. Class 2.

(1) Visible (400 nm to 700 nm) CW laser devices that can emit a power exceeding the AEL for Class 1 for the maximum possible duration inherent to the design of the laser or laser system but not exceeding 1 mW.

(2) Visible (400 nm to 700 nm) repetitively pulsed laser devices that can emit a power exceeding the appropriate AEL for Class 1 for the maximum possible duration inherent to the design of the laser device but not exceeding the AEL for a 0.25 s exposure.

c. Class 2a. A visible (400 nm to 700 nm) laser or laser system that is not intended for intrabeam viewing and does not exceed the exposure limit for 1000 s of viewing time.

d. Class 3a. Class 3a lasers or laser systems have—

(1) An accessible output power or energy between 1 and 5 times the lowest appropriate AEL for Class 2 for visible wavelengths, and between 1 and 5 times the AEL for Class 1 for all other wavelengths.

(2) Do not exceed the appropriate exposure levels as measured over the limiting aperture (2.5 $mW{\cdot}cm^{-2}$ for visible CW lasers).

e. Class 3b.

(1) Infrared (1.4 μm to 1 mm) and ultraviolet (200 nm to 400 nm) laser devices. Emit a radiant power in excess of the AEL Class 1 for the maximum possible duration inherent to the design of the laser device. Cannot emit an average radiant power of 0.5 W or greater for T_{max} greater than 0.25 s, or a radiant exposure of 10 $J{\cdot}cm^{-2}$ within an exposure time of 0.25 s or less.

(2) Visible (400 nm to 700 nm) CW or repetitive pulsed laser devices. Produce a radiant power in excess of the AEL Class 1 for a 0.25 s exposure (1 mW for a CW laser). Cannot emit an average radiant power of 0.5 W or greater for T_{max} greater than 0.25 s.

(3) Visible and near-infrared (400 nm to 1400 nm) pulsed laser devices. Emit a radiant energy in

APPENDIX E
DETAILED TECHNICAL HAZARD ANALYSIS

Section I. GENERAL EVALUATIONS

E–1. 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 be applied to the rest of the body.

E–2. Viewing the Primary Beam (Direct Intrabeam Viewing). The worst possible situation would exist if the eye were focused at infinity and the beam concentrated at the retina in a diffraction spot (wavelengths of 0.4 μm to 1.4 μm). The corneal irradiance or radiant exposure at the point of interest may be calculated using equations 8a and 8b of this appendix.

E–3. Viewing the Reflected Beam. *a. Specular Reflection.* Specular reflection requires a mirror-like surface. If the reflecting surface is 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 intensity arriving at the cornea is less and may be readily 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. This effect is shown graphically in figure E–1. The curves in figure E–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°. The practical significance of figure E-1 is shown in figure E-2 where a collimated laser beam is incident upon a plate glass window.

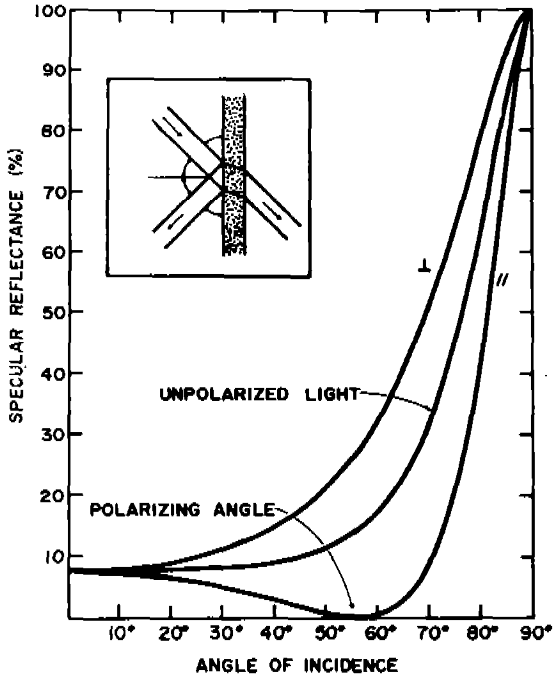


Figure E–1. Specular reflectance from both surfaces of plate glass having an index of refraction of 1.5.

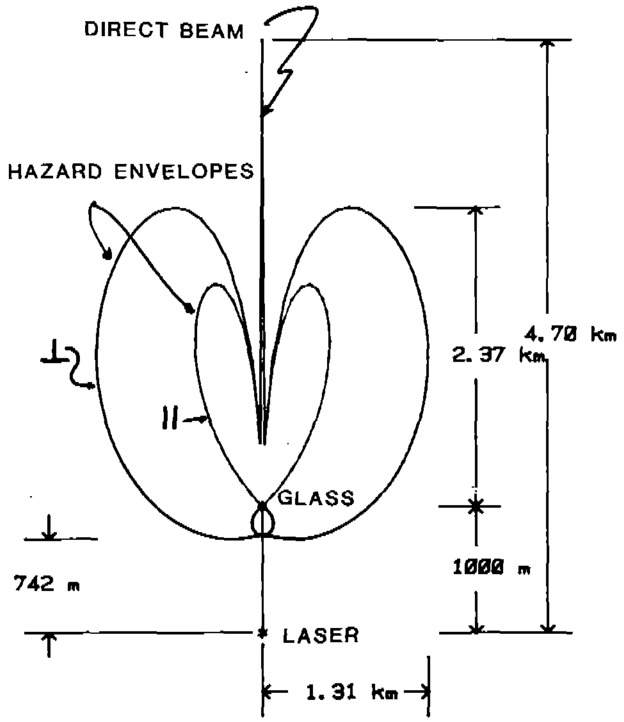


Figure E–2. Hazard envelopes created by a laser beam incident upon a vertically oriented flat (30 cm × 15 cm) glass surface.

b. Diffuse reflection. The reflection from a flat diffuse surface obeys Lambert's Law [see equation (5) below] which relates the energy or power per solid angle to the radiant energy or power at the surface (i.e., essentially the "inverse square law"). A maximum incident radiant exposure or irradiance for the 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 E-6. Hazard classification and determination of exposure limits may require the use of equations in section III. Equations useful in estimating exposure at significant distances from the laser and optically aided viewing are presented in section IV. Figures E-3 through E-5 illustrate ocular viewing conditions.

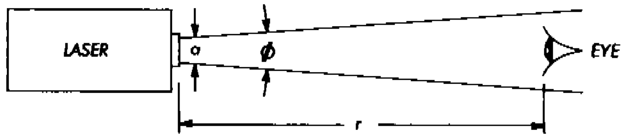


Figure E–3. Inbrabeam viewing—direct beam (primary beam).

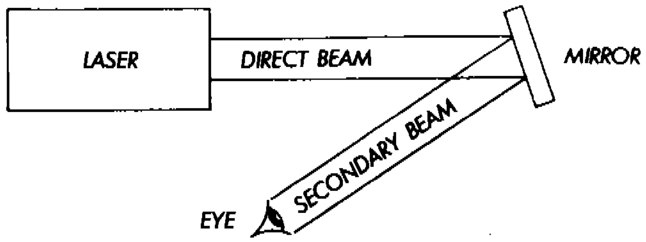


Figure E–4a. Intrabeam viewing—specularly reflected from flat surface (secondary beam).

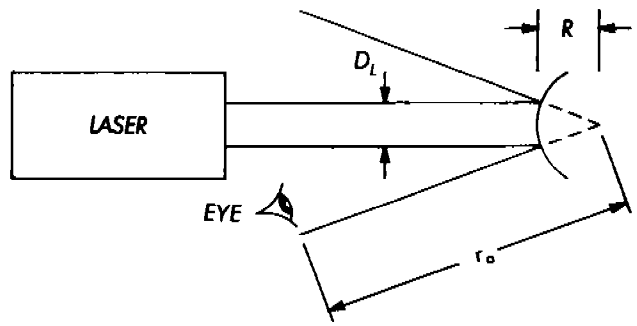


Figure E–4b. Intrabeam viewing—specularly reflected from curved surface (secondary beam).

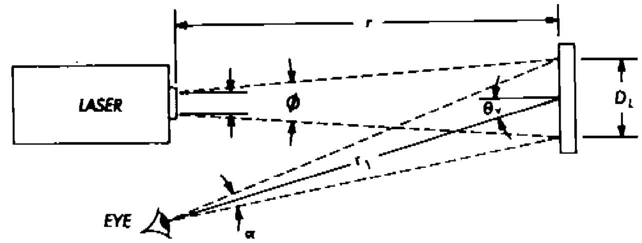


Figure E–5. Extended source viewing—normally a diffuse reflection.

Section II. MATHEMATICAL SYMBOLS

E–6. Definitions.

a	=	Diameter of emergent laser beam (cm)
d	=	Diameter of measuring aperture (cm)
d_e	=	Diameter of the pupil of the eye (varies from approximately 0.2 to 0.7 cm)
d_{min}	=	Limiting object size of extended object (cm)
D_e	=	Diameter of the exit pupil of an optical system (cm)
D_L	=	Diameter of laser beam at range r (cm)
D_o	=	Diameter of objective of an optical system (cm)
e	=	Base of natural logarithms, 2.718
E, H	=	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, respectively
EL	=	Exposure limit
EEL	=	Effective exposure limit
E_o, H_o	=	Emergent beam radiant exposure (H_o) or irradiance (E_o) at zero range (units as for E, H)
f	=	Effective focal length of eye (1.7 cm)
f(x)	=	Fraction of beam power or energy passing through an aperture of diameter, d
F	=	Pulse repetition frequency (PRF), s^{-1} or Hz
G	=	Ratio of retinal irradiance or radiant exposure received by an optically aided eye to that received by unaided eyes
L	=	Radiance of an extended source ($W \cdot cm^{-2} \cdot sr^{-1}$)
L_P	=	Integrated radiance of an extended source ($J \cdot cm^{-2} \cdot sr^{-1}$)
n	=	Number of pulses in a train of pulses
NOHD	=	Nominal ocular hazard distance
NOHD*	=	Nominal ocular hazard distance when optical aids are used
P	=	Magnifying power of an optical system

comparison with the exposure limit applicable for the duration of the entire exposure (para C–5*b*).

STEP 3. The results of STEPS 1 and 2 shall then be compared and the limitation which provides the lowest total exposure applied.

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 MHZ and t = 10 ns (i.e., 10^{-8} s). Following *b* above, consider at least two criteria:

STEP 1. *Individual pulse limitation.*

First determine the reduced exposure limit for an individual pulse. For a PRF greater than 1 kHz, the reduction factor from figure C–5 is 0.06 for a 10 ns pulse.

Exposure Limit/Pulse:

$$H_i = 0.06 \times (5 \times 10^{-7}\ J{\cdot}cm^{-2}) = 3 \times 10^{-8}\ J{\cdot}cm^{-2} = 30\ nJ{\cdot}cm^{-2}$$

On this basis the exposure limit for the total exposure is—

Exposure Limit/Train:

$$H = H_i \cdot F \cdot T = (3 \times 10^{-8}\ J{\cdot}cm^{-2})\ (10^7\ Hz)\ (0.25\ s) = 7.5 \times 10^{-2}\ J{\cdot}cm^{-2} = 75\ mJ{\cdot}cm^{-2}$$

STEP 2. *Average radiant exposure limitation.*

For a single exposure of 0.25 s, the exposure limit is (from table C–1)—

Exposure Limit: $H \leq 6.3 \times 10^{-4}\ J{\cdot}cm^{-2} = 0.63\ mJ{\cdot}cm^{-2}$

STEP 3. *Conclusion.*

Since STEP 2 above is the limiting case (more restrictive), the correct exposure limit is—

Exposure Limit:

$$H = 6.3 \times 10^{-4}\ J{\cdot}cm^{-2} \text{ in 0.25 seconds}$$

$$\text{or } E_{(avg)} = \frac{H}{T} = \frac{6.3 \times 10^{-4}}{0.25\ s}\ J{\cdot}cm^{-2} = 2.5\ mW{\cdot}cm^{-2}$$

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

Determine the intrabeam viewing exposure limit for a 905 nm (GaAs) laser which has t = 100 ns (i.e., 10^{-7} s) and PRF = 1 kHz. 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. From figure C–5, the reduction factor for PRF = 1 kHz is 0.06 and from figure C–4 the wavelength correction factor is 2.57 at 905 nm.

STEP 1. *Individual pulse limitation.*

From table C–1, the exposure limit is—

Exposure Limit Pulse:

$$H_i = (2.5)\ (0.06)\ (5 \times 10^{-7}\ J{\cdot}cm^{-2}) = 7.7 \times 10^{-8}\ J{\cdot}cm^{-2} = 75\ nJ{\cdot}cm^{-2}$$

and on this basis the exposure limit for the entire train would be—

Exposure Limit Train:

$$H \leq (10\ s)\ (10^3\ Hz)\ (7.7 \times 10^{-8}\ J{\cdot}cm^{-2}) = 7.7 \times 10^{-4}\ J{\cdot}cm^{-2} = 0.75\ mJ{\cdot}cm^{-2}$$

STEP 2. *Average power limitation.*

From table C–1 the exposure limit is—

$$H_i = 1.8\ C_A t^{3/4}\ mJ{\cdot}cm^{-2}$$

$$C_A = 2.57 \text{ @ } 905\ nm$$

$$t^{3/4} = 10^{3/4} = 5.62$$

$$H_i = (1.8)(2.57)(5.62)\ mJ{\cdot}cm^{-2}$$

$$= 2.6 \times 10^{-2}\ J{\cdot}cm^{-2} = 26\ mJ{\cdot}cm^{-2}$$

STEP 3. *Conclusion.*

Clearly the limitation in STEP 1 determines the exposure limit.

Exposure Limit/Train: $H = 7.7 \times 10^{-4}\ J{\cdot}cm^{-2}$

EXAMPLE 5. *Low PRF, Long Pulse, Repetitively Pulsed Visible Laser.*

Determine the exposure limit for a 632.8 nm (HeNe) laser where T = 0.25 s, t = 10^{-3} s, and PRF = 100 Hz.

STEP 1. *Individual pulse limitation.*

Following paragraph C–5*b*, find the total *on-time*. T_i for the 0.25 s exposure is—

$$T_i = t \cdot PRF \cdot T$$

$$T_i = (10^{-3}\ s)\ (100\ Hz)(0.25\ s) = 2.5 \times 10^{-2}\ s$$

From table C–1, the exposure limit for the exposure time T_i is—

$$H = 1.8t^{3/4}\ mJ{\cdot}cm^{-2}$$

$$= 1.8(2.5 \times 10^{-2}\ s)^{3/4}\ mJ{\cdot}cm^{-2}$$

$$= 0.11\ mJ{\cdot}cm^{-2}$$

$$H_i = \frac{0.11\ mJ{\cdot}cm^{-2}}{25 \text{ pulses}} = 4.5\ \mu J{\cdot}cm^{-2}$$

now $H_i \times PRF$ = Average power limit

$$(4.5 \times 10^{-6})(100) = 4.5 \times 10^{-4}\ W{\cdot}cm^{-2}$$

$$= 0.45\ mW{\cdot}cm^{-2}$$

STEP 2. *Average power limitation.*

For a 0.25 s exposure, the exposure limit from table C–1 is —

$$H = 1.8t^{3/4}\ mJ{\cdot}cm^{-2} = 1.8(0.25)^{3/4}\ mJ{\cdot}cm^{-2} = 0.64\ mJ{\cdot}cm^{-2}$$

For a 0.25 s exposure, this results in an average power exposure limit of—

b. The brightness units. The radiometric quantities of *radiance* $W \cdot cm^{-2} \cdot sr^{-1}$ and *integrated radiance* $J \cdot cm^{-2} \cdot sr^{-1}$ are used for extended sources since these quantities, which describe the source directly, determine the irradiance distribution of the retinal image due to an extended source. The radiance of a diffuse reflection is directly related to the incident beam irradiance and the latter quantity may be more easily applied in practical hazard evaluation. Table D–1 presents the incident beam radiant exposures corresponding to integrated radiance exposure limits.

c. Applying the limiting angle (α_{min}). This angle is used to determine if viewing distances (r_1) in a given situation may be sufficiently close to apply extended source criteria. Figure E–5 shows the relation of r_1, D_L, and α_{min}.

(3) $$\alpha = \frac{D_L \cos\theta_v}{r_1} ; \quad \alpha_{min} = \frac{D_L \cos\theta_v}{r_{1max}},$$

$$\text{for } \theta_v \leq 0.37 \text{ radian } (21°)$$

EXAMPLE 9. *Finding the Maximum Distance Where the Extended Source Protection Standard Applies.*

Find the maximum distance r_{1max} for a visible laser having an emergent beam diameter a = 1 cm, a beam divergence $\phi = 10^{-4}$ radian, and a pulse duration of 20 μs. A diffuse matte target is placed 100 cm from the beam exit of the laser (i.e., the target distance r = 100 cm). The relation of D_L to the emergent beam divergence and diameter is—

(4) $D_L = a + r\phi$

At short target distances D_L is clearly the same as a or 1 cm and using equation 3 and finding α_{min} from figure C–3—

$$r_{1max} = \frac{a}{\alpha_{max}} = \frac{1 \text{ cm}}{(1.6 \times 10^{-3} \text{ rad})} = 625 \text{ cm}$$

Therefore, at viewing distances less than 625 cm from the target, the applicable exposure limit from table C–2 is 2.8×10^{-1} $J \cdot cm^{-2} \cdot sr^{-1}$ and for greater distances the applicable exposure limit from table C–1 is 5×10^{-7} $J \cdot cm^{-2}$. This example illustrates that for most pulsed lasers the extended source exposure limits are applicable in indoor areas such as laboratories. Exceptions would be focused beam diffuse reflections such as those occurring in microdrilling. For visible CW lasers where the exposure time could be 0.25 s or greater and where a is often only 0.1 to 0.2 cm, α_{min} is sufficiently great (10–24 mrad) that the maximum r_1 to apply these protection standards would be only a few cm and the intrabeam exposure limits would be more relevant. For a = 0.1 cm, and α_{min} = 24 mrad, r_{1max} = 4.2 cm.

EXAMPLE 10. *Extended Source Exposure Limits for Diffuse Reflections Expressed as Incident Beam Irradiance or Radiant Exposure.*

In most cases it is simplest to consider the incident beam irradiance or radiant exposure as being capable or not capable of producing a hazardous diffuse reflection rather than have to deal with less familiar radiometric quantities such as radiance. Consider the laser defined in example 8. Since the extended source exposure limit is expressed as an integrated radiance we need to know the beam radiant exposure at the target which produces this integrated radiance. The relation is—

(5) $$L_p = \frac{H\rho_\lambda}{\pi} \quad \text{or} \quad H = \frac{\pi L_p}{\rho_\lambda}$$

Hence the exposure limit expressed for a 100 percent reflectance white diffuse target is—

$$H = \frac{(3.14)(2.8 \times 10^{-1} \text{ J} \cdot \text{cm}^{-2} \text{ sr}^{-1})}{1.0}$$

$$= 0.88 \text{ J} \cdot \text{cm}^{-2}$$

NOTE

Equation 5 is strictly true only for a theoretically perfect Lambertian surface; however, unless a surface has a highly glossy sheen, it may be considered sufficiently "diffuse" to apply this equation and the diffuse surface exposure limits. The above result could have been obtained by interpolating the values in column 4 of table D–1 between 10^{-5} s and 10^{-4} s.

EXAMPLE 11. *Spectral Corrections for Near Infrared Laser Protection Standards.*

A gallium-arsenide laser operating at room temperature has a peak wavelength at 904 nm. What is the exposure limit for a single pulse of 200 ns duration? Using figure C–4, the spectral correction factor is 2.57. Using table C–1, the exposure limit for direct viewing of the source is (2.57) (5×10^{-7} $J \cdot cm^{-2}$) = 1.3×10^{-6} $J \cdot cm^{-2}$ for a single pulse. Similarly, the extended source exposure limit for sources subtending an angle greater than 3.3 mrad (from table C–2 for 200 ns) is (2.57)(5.8×10^{-2} $J \cdot cm^{-2} \cdot sr^{-1}$) = 1.5×10^{-1} $J \cdot cm^{-2} \cdot sr^{-1}$.

NOTE

Unlike gas or solid-state lasers, this semiconductor laser could be an extended source at close viewing range within the beam if the line source was magnified by a projector lens.

One way to calculate beam divergence is to compare the beam diameter at a distance to the initial beam diameter.

(9) $$\phi = \frac{D_L - a}{r} \quad \text{for small } \phi$$

EXAMPLE 16. *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.

a. Maximum beam irradiance.

$$E_0 = \frac{1.27\Phi}{a^2} = \frac{1.27(5 \times 10^{-3}\ W)}{(0.8)^2}$$

$$= 10\ mW \cdot cm^{-2}$$

b. Maximum beam irradiance averaged over 7 mm.

$$E_0 = 2.6(5 \times 10^{-3}\ W)\left[1 - e^{1/2\ (0.8)^2}\right]$$

$$= 7\ mW \cdot cm^{-2}$$

EXAMPLE 17. *Finding the Beam Diameter.*

a. 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. 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 $\sqrt{2} = 1.41$, hence—

$$a = \frac{0.3\ cm}{\sqrt{2}} = 0.21\ cm$$

b. 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 throughput power of 1 mW passing through a 7-mm aperture.

$$a = \sqrt{\frac{-(0.7)^2}{\ln(1 - 0.2)}} = 1.5\ cm$$

EXAMPLE 18. *Finding the Portion of a Beam Which Will Pass Through an Aperture.*
Find the maximum percentage of total power of a 3 mW HeNe laser which will pass through a 7-mm aperture if the beam diameter specified at $1/e^2$ points is 1.6 cm. The fraction of the total beam which passes through an aperture of diameter d = 7 mm is—

(10) $$f(x) = 1 - e^{-d_e^2/a^2}$$

as shown in figure E–6, where a = beam diameter.

The beam diameter at 1/e $= 1.6/\sqrt{2}$
$= 1.1$ cm
$f(x) = 1 - e^{-0.49/(1.1)^2} = 0.33$
$= 1$ mW

EXAMPLE 19. *632.8 nm Visible Laser (HeNe).*
Classify a 632.8 nm visible laser (HeNe) 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 10^{-4} J·pulse^{-1}), and a beam diameter of one cm. The recycle time of the laser is 5 s (maximum PRF = 0.2 Hz). Since the device is pulsed with an exposure duration of 0.1 s, the applicable exposure limit for intrabeam viewing from figure C–1 is 3.2×10^{-3} W·cm^{-2} or 3.2×10^{-4} J·cm^{-2}. Using equation 6, the emergent beam radiant exposure per pulse is 1.27×10^{-4} J·cm^{-2} which is less than half the exposure limit. In the absence of biologic data and exposure limits for exposures repeated at PRFs less than 1 Hz, consider the exposures linearly additive. Following this rule, at least two exposures are possible after considering all three aspects in a hazard evaluation (chap 3, sec I). The prudent approach is to apply a WARNING label to the device with the words DO NOT STARE CONTINUOUSLY INTO LASER BEAM.

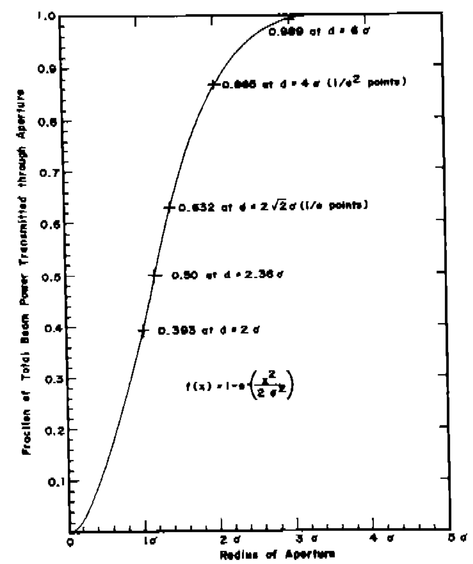


Figure E–6. Fraction of a Gaussian laser beam passing through a circular aperture.

EXAMPLE 23.
Find the maximum reflected radiant exposure from a diffuse target of reflectance 0.6 which would return a distance of 10 meters to the operator of a 0.1 J laser:

$$(\cos\theta_v = 1)$$

$$H = \frac{(0.1J)(0.6)}{(3.14)(10^3\ cm)^2} = 19.1\ nJ\cdot cm^{-2}$$

EXAMPLE 24.
Find the hazardous intrabeam viewing distance (assume a 10 s exposure) for looking at a diffuse target having reflectivity p = 0.9 from a laboratory argon laser with $\Phi = 2$ W and a = 2 mm. Since the emergent beam irradiance is more than 6.3 $W\cdot cm^{-2}$ for a 10-second exposure we conclude that $r_{1(hazard)}$ must be greater than d_{min}/α. Hence (the 10 s exposure limit is 1×10^{-3} $W\cdot cm^{-2}$) ($\cos\theta_v = 1$)—

$$r_{1(hazard)} = \frac{\phi\rho\lambda}{\pi E} = \frac{(2)(0.9)}{(\pi)(10^{-3})} = 24\ cm$$

E–17. Viewing Aided by an Optical System. The optical gain (G) is defined as the ratio G of radiant exposure or irradiance at the retina to that when viewing by the unaided eye:

a. For intrabeam viewing of the primary beam and specular reflections of the primary beam where $D_L > D_o$ (or a diffuse laser spot is unresolved by the eye and optical system) and the laser operates within the wavelength range of 400–1400 nm:

(16a & 16b)

$$G = 2.04\ D_o^2 \quad \text{for } 0.7\ cm \leq D_e$$

$$G = \frac{D_o^2}{D_e^2} = P^2 \quad \text{for } 0.7\ cm \geq D_e$$

EXAMPLE 25. *Finding the Extended NOHD (NOHD*) When Optical Aids Are Used.*

Calculate the NOHD* from a laser beam similar to that in Example 22 when the laser is viewed through 7 × 50 binoculars.

STEP 1. *Calculate the gain factor, G.*
Since $P = D_o/D_e$

$$D_e = \frac{50}{7} = 7.14\ mm$$

From paragraph E–17*a*, $G = \frac{D_o^2}{D_e^2} = p^2 = 49$

STEP 2. *Insert the gain factor into equation 14 for NOHD.*

(17a & 17b)

$$NOHD^*(v) = 1/\phi\left\{\sqrt{\frac{1.27\Phi G}{EL}} - a\right\}$$

$$NOHD^*(v) = 1/\phi\left\{\sqrt{\frac{1.27QG}{EL}} - a\right\}$$

STEP 3. *Calculate NOHD*.*

$$NOHD(v) = \frac{1}{(5 \times 10^{-4})}\left\{\sqrt{\frac{1.27(0.05)49}{5 \times 10^{-7}}} - 1.0\right\} = 50\ km$$

From table E–1, NOHD* = 26 km

b. As an alternate method for calculating the corneal irradiance or radiant exposure averaged over a 7-mm pupillary diameter when optical aids are used, the following relations may be used:

(18a–18d)

$$\left.\begin{aligned} E_o &= 2.6\,\Phi\left[1 - e^{-D_o^2/D_L^2}\right]e^{-\mu r} \\ H_o &= 2.6Q\left[1 - e^{-D_o^2/D_L^2}\right]e^{-\mu r}\end{aligned}\right\} D_e \leq 7\ mm$$

$$\left.\begin{aligned} E_o &= \frac{1.27\Phi}{D_e^2}\left[1 - e^{-D_o^2/D_L^2}\right]e^{-\mu r} \\ H_o &= \frac{1.27Q}{D_e^2}\left[1 - e^{-D_o^2/D_L^2}\right]e^{-\mu r}\end{aligned}\right\} D_e > 7\ mm \text{ and } D_L > D_o$$

NOTE

When $D_L < D_o$ use equations 18a and 18b.

c. For indirect viewing of a diffuse reflection or viewing extended objects only (i.e., object subtends angle greater than 0.6 milliradian when magnified)—

(19a & 19b)

$$G = \frac{D_o^2}{P^2(0.7)^2} \leq 1 \text{ for } 7\ cm \geq D_e$$

and

$$G = \frac{D_o^2}{P^2 D_e^2} = 1 \quad \text{for } 0.7\ cm \leq D_e$$

NOTE

The ratio G is affected by the optical transmission τ of the instrument, but this is normally not known. If the transmission is

E–18. Corneal Radiant Exposure for Single Exposure from a Scanning Laser Beam. Repetitive pulsed exposures depend upon geometrical considerations, scan rate, and frame rate.

(20a & 20b)

$$H = \frac{1.27\Phi e^{-\mu r}}{(a + r\phi)^2} \cdot \frac{d_e}{rS\theta_s} \quad \text{for } d_e > (a + r\phi)$$

or

$$H = \frac{1.27\,\Phi\, e^{-\mu r}}{(a+r\phi)(rS\theta_s)} \quad \text{for } d_e \leq (a+r\phi)$$

For the applicable exposure limits refer to the repetitive nature of the exposure and the exposure duration of a single pulse where—

(21a & 21b)

$$t = \frac{(a+r\phi)}{rS\theta_s} \quad \text{for } d_e \leq (a+r\phi)$$

or

$$t = \frac{d_e}{rS\theta_s} \quad \text{for } d_e > (a+r\phi)$$

and the PRF is S if each scan passes over the eye.

EXAMPLE 28.

Find the exposure of a scanning HeNe laser system having the following parameters:

a = 0.1 cm, ϕ = 5 mrad, Φ = 5mW,
θ_s = 0.1 rad, and S = 30 scans/s for an intrabeam viewing distance r = 200 cm.

STEP 1. The beam diameter $D_L = (a+r\phi) = (0.1 + 1) = 1.1$ cm, hence apply the H and t equations shown above.

STEP 2. The PRF at the eye is 30 pulses per second and the exposure time is—

$$t = \frac{0.1 + (200)(5 \times 10^{-3})}{(200)(30)(0.1)} = \frac{1.1}{600} = 1.8 \text{ ms.}$$

STEP 3. The radiant exposure is—

$$H = \frac{(1.27)(5 \times 10^{-3})(1)}{(0.1 + 1)(200)(30)(0.1)} = 9.6\ \mu\text{J}\cdot\text{cm}^{-2}.$$

STEP 4. The average irradiance at the cornea is—

$E_{avg} = H{\cdot}S = (9.6 \times 10^{-6})\ (30) = 0.29$ mW·cm^{-2}

STEP 5. The applicable exposure limit for a 0.25 s exposure is determined by the cumulative exposure of almost eight pulses, or (8) $(9.6 \times 10^{-6}$ J·cm$^{-2})$ = 77 μJ·cm^{-2}. This radiant exposure must be compared with the exposure limit for a single pulse of duration t = (8) (1.8 ms) = 15 ms, which from figure C–1a, or by calculation (Example 1) is 77 J·cm^{-2}. Hence, the exposure is permissible for momentary (unintentional) viewing.

E–19. Exposure Limit from a Multiwavelength Laser. Calculating the exposure from a multiple wavelength laser requires a knowledge of the relative irradiance or radiant exposure from each wavelength present. If each wavelength has a different divergence then the composite exposure level will also be a function of the distance from the laser. The following relationships may be used at any particular distance:

(22a & 22b)

$$EEL = \Sigma E_i / \Sigma (E_i/EL_i)$$

$$EEL = \Sigma H_i / \Sigma (H_i/EL_i)$$

EXAMPLE 29.

Determine the effective exposure limit (EEL) for single-pulse exposure to a Nd:YAG laser that is frequency doubled and emits 70 mJ at 1064 nm and 10 mJ at 532 nm. The pulse width is 10 ns and a = 1 cm. Since both laser wavelengths are in the retinal hazard region (400 nm to 1400 nm), the EEL must account for the additivity of the two wavelengths. The EEL depends on the relative amounts of each wavelength in the total laser output. The above laser is not as hazardous as an 80 mJ laser operating at 532 nm or as safe as an 80 mJ laser operating at 1064 nm. The EEL may be calculated from the following:

$$EEL = \Sigma H_i / \Sigma H_i / EL_i$$

where—

H_i = D_L radiant exposure averaged over 7 mm if a ≤7 mm; if a >7 mm then average over a.

EL_i = the exposure limits for each wavelength.

$$H_1 = \frac{7 \times 10^{-2}\text{J}}{\frac{\pi(1)^2}{4}} = (1.27)(7 \times 10^{-2})$$

$$= 8.9 \times 10^{-2}\ \text{J}\cdot\text{cm}^{-2}$$

$$H_2 = \frac{10^{-2}\text{J}}{\frac{(1)^2}{4}} = 1.27 \times 10^{-2}\ \text{J}\cdot\text{cm}^{-2}$$

$$\Sigma H_i = 8.9 \times 10^{-2} + 1.27 \times 10^{-2}$$

$$= 1.02 \times 10^{-1}\ \text{J}\cdot\text{cm}^{-2}$$

$$EL_1 = 5 \times 10^{-6}\ \text{J}\cdot\text{cm}^{-2}$$

$$EL_2 = 5 \times 10^{-7}\ \text{J}\cdot\text{cm}^{-2}$$

E–24. Equation 4. Laser beam diameter downrange from laser.

$$D_L = a + r\Phi$$

E–25. Equation 5. Integrated radiance, L_p, as a function of radiant exposure, H, on a perfect diffuse surface; and radiant exposure as a function of integrated radiance from the illuminated spot.

$$L_p = \frac{H\rho_\lambda}{\pi}$$

$$H = \frac{\pi L_p}{\rho_\lambda}$$

E–26. Equation 6. Central beam irradiance, E_o, and radiant exposure, H_o.

$$H_o = \frac{1.27Q}{a^2}$$

$$E_o = \frac{1.27\Phi}{a^2}$$

E–27. Equation 7. Central beam irradiance, E_o, and radiant exposure, H_o, averaged over a 7-mm aperture.

$$E_o = 2.6\Phi\left[1 - e^{-1/2a^2}\right]$$

$$H_o = 2.6Q\left[1 - e^{-1/2a^2}\right]$$

E–28. Equation 8. Beam diameter in relation to fraction of total beam power passing through an aperture for Gaussian beam.

$$a = \sqrt{\frac{-d^2}{\ln[1 - f(x)]}}$$

$$D_L = \sqrt{\frac{-d^2}{\ln[1 - f(x)]}}$$

E–29. Equation 9. Beam divergence in relation to the initial beam diameter and the beam diameter downrange.

$$\phi = \frac{D_L - a}{r}$$

E–30. Equation 10. Fraction of beam power passing through aperture.

$$f(x) = 1 - e^{-d^2/a^2}$$

E–31. Equation 11. Beam irradiance, E, or radiant exposure, H, for nondiverging beam at range, r.

$$E = E_o e^{-\mu r}$$

$$H = H_o e^{-\mu r}$$

E–32. Equation 12. Average irradiance, E, at range, r, (direct circular beam) or radiant exposure, H, at range.

$$E = \frac{1.27\Phi e^{-\mu r}}{(a + r\phi)^2}$$

$$H = \frac{1.27Qe^{-\mu r}}{(a + r\phi)^2}$$

E–33. Equation 13. Minimum beam diameter at range, r.

$$D_L = a + r\phi \quad \text{for small } \phi$$

E–34. Equation 14. Nominal ocular hazard distance from a CW laser or a pulsed laser in a vacuum.

$$\left.\begin{array}{l} NOHD(v) = 1/\phi \left\{\sqrt{\dfrac{1.27\Phi}{EL}} - a\right\} \\ NOHD(v) = 1/\phi \left\{\sqrt{\dfrac{1.27Q}{EL}} - a\right\} \end{array}\right\} \text{without atmospheric attentuation}$$

E–35. Equation 15. Reflected irradiance, E, or radiant exposure, H, for diffuse reflector (for $r_1 >> D_L$).

$$E = \frac{\Phi\rho_\lambda \cos\theta v}{\pi r_1^2}$$

$$H = \frac{Q\rho_\lambda \cos\theta v}{\pi r_1^2}$$

E–36. Equation 16. Optical gain factor for direct viewing.

$$G = 2.04\, D_o^2 \qquad 0.7 \text{ cm} \geq D_e$$

$$G = \frac{D_o^2}{D_e^2} = P^2 \qquad 0.7 \text{ cm} \leq D_e$$

APPENDIX F
LASER PROTECTIVE EYEWEAR

F–1. Background. Laser protective eyewear is presently available from several commercial sources and in many varieties. A standard anti-laser goggle is being developed by the Army. Several factors should be considered in determining whether eyewear is necessary and, if so, selecting the proper eyewear for a specific situation. At least two output parameters of the laser must be known, and knowledge of environmental factors such as ambient lighting and the nature of the laser operation is also required. Laser eye protection generally consists of a filter plate or stack of filter plates, or two filter lenses that selectively attenuate at specific laser wavelengths, but transmit as much visible radiation as possible. Eyewear is available in several designs: Spectacles, coverall types with opaque side-shields, coverall types with somewhat transparent side-shields, aviator frames with no side-shields, and laboratory style with flat glass absorbers.

F–2. Operational Requirements for Laser Eye Protection. *a.* The experience gained by the USAEHA from evaluating ocular hazards of a large variety of field and laboratory lasers shows that *requirements for eye protection vary considerably.* The primary usefulness of laser eye protection is in testing of and training with laser devices.

b. Laser eye protectors are normally not recommended for *flight crews of aircraft* equipped with laser rangefinders and target designators. 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 goggles from the normally very low probability of exposure from a reflected laser beam. However, if a hazardous specular reflection is likely to be directed toward the aircraft, or if a laser beam is to be intentionally directed at the aircraft then aviators can be required to wear eye protectors with high visual transmission. (Side-shields, which reduce peripheral vision, may not be necessary due to the very low probability of a hazardous double reflection exposure at typical engagement ranges.)

c. At present, it is felt that *armored vehicle crews* do not require personal eye protection within vehicles. However, magnifying optical devices within armored vehicles which could transmit the beam to a crewmember should be equipped with laser protective filters. If armored crews were to be outside of the vehicle, personal eye protectors are desirable in certain instances where specular reflections are expected. If an armored vehicle is the target in laser tests or exercises, personal eye protection for the driver, the commander, and other exposed personnel may be required.

d. In *test and training activities,* eye protection has been required for personnel downrange within the laser beam target area and for other personnel if the target area cannot be cleared of specular 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.

e. For *indoor shop or laboratory environments,* eye protection is required for Class 4 lasers and where specular reflections of Class 3 lasers are not controlled. However, eye protection has not been recommended for holographic viewing and optical alignment procedures if reasonable precautions are taken.

f. If *curved protective filters* are required for personnel in a laser target area, personnel in the vicinity of the laser and elsewhere would not also require eye protection. 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.

g. Proper *indoctrination of laser operators* not to fire at personnel and the low probability of exposure to a specular reflection should preclude the need for laser eye protection from US laser equipment in combat, except in unusual instances.

h. Recommendations for operational hazard controls and eye protection requirements for *specific Army laser systems* are given in AR 385–63.

F–3. Eyewear Parameters. The factors that shall be considered before choosing laser safety eyewear are:

a. Wavelength. The wavelength(s) of laser radiation limits the type of eye shields to those that prevent the particular wavelength(s) from reaching the eye. It is emphasized that many lasers emit more than one wavelength and that each wavelength shall be considered. Considering the wavelength corresponding to the greatest output intensity is not always adequate. For instance, a helium-neon laser may emit 100 mW at 632.8 nm and only 10 mW at 1150 nm, but safety goggles which absorb the 632.8-nm wavelength may absorb relatively little or essentially nothing at the 1150-nm wavelength.

b. Optical density. Optical density is a parameter for specifying the attenuation afforded by a given thickness of any transmitting medium. Since laser beam intensities may be a factor of a thousand or a incident beam and I is the irradiance or radiant exposure of the transmitted beam. Thus, a filter attenuating a beam by a factor of 1000 or 10^3 has an optical density of 3, and attenuating a beam by 1,000,000 or 10^6 requires an optical density of 6. The required optical density is determined by the maximum laser beam irradiance or radiant exposure to which the individual could be exposed. The optical density of two highly absorbing filters when stacked is essentially the sum of two individual optical densities.

c. Laser beam intensity. The maximum laser beam radiant exposure in $J{\cdot}cm^{-2}$ for pulsed lasers or maximum laser beam irradiance in $W{\cdot}cm^{-2}$ for continuous-wave lasers cannot always be readily determined. If the beam is never focused and is larger than the diameter of the eye's pupil, the output energy per unit area or power per unit area should be the guiding value. If the beam is focused or if the beam cannot be observed at the output, the maximum total beam energy or power output shall be used.

d. Visible transmittance of eyewear. Since the object of laser protective eyewear is to filter out the laser wavelengths while transmitting as much of the visible light as possible, visible (or luminous) transmittance should be noted. A low visible transmittance (usually measured in percent) creates problems of eye fatigue and may require an increase in ambient lighting in laboratory situations. However, adequate optical density at the laser wavelengths should not be sacrificed for improved visible transmittance. For nighttime viewing conditions, the effective visible transmittance will be different since the spectral response of the eye is different. Figure F–1 shows the scotopic (night vision) and photopic (day vision) responses of the eye. Blue-green filter lenses, therefore, have higher scotopic transmission values than red or orange lenses and vice-versa.

e. Laser filter damage threshold (maximum irradiance). At very high beam intensities, filter materials which absorb the laser radiation are damaged; thus, it 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 $J{\cdot}cm^{-2}$ and 10 $J{\cdot}cm^{-2}$ for plastics and dielectric coatings. Irradiances from CW lasers which would cause filter damage are in excess of those which would present a serious fire hazard and, therefore, need not be considered (i.e., personnel should not be permitted in the area of such lasers).

F–4. Methods of Construction. *a.* There are basically two effects that are utilized to selectively filter out laser wavelengths. Filters are designed to make use of selective spectral absorption by colored glass or plastic, or selective reflection from dielectric coatings on glass, or both. Each method has its advantages.

b. The simplest method of fabrication is to use colored glass absorbing filters that are generally the most effective in resisting damage from wear and from very intense laser sources. Unfortunately, most absorbing filters are not case-hardened to provide impact resistance, but clear plastic sheets are generally placed behind the glass filter.

c. The advantage of using reflective coatings is that they can be designed to selectively reflect a given wavelength while transmitting as much of the rest of the visible light as possible. However, some angular dependence of the spectral attenuation factor is generally present.

d. The advantages of using absorbing plastic filter materials are greater impact resistance, lighter weight, and ease of molding into curved shapes. The disadvantages are that they are more readily scratched, quality control appears to be more difficult, and the organic dyes used as absorbers are more readily affected by heat and ultraviolet radiation and may saturate or bleach under Q-switched laser irradiation.

F–5. Selecting appropriate eyewear.

STEP 1. Determine wavelength(s) of laser output.

STEP 2. Determine required optical density (table 4–1) or required optical densities (or alternatively dB of attenuation, or attenuation factors) for various laser beam intensities that could be incident upon safety eyewear. To determine the maximum incident beam intensity, consider the following:

a. If the emergent beam is not focused down to a smaller spot, and is greater than 7 mm in diameter, the emergent beam radiant exposure or irradiance may be considered the maximum intensity that could reach the unprotected eye, and is thus used in table 4–1.

b. If the emergent beam is focused after emerging from the laser system or if the emergent beam diameter is less than 7 mm in diameter, assume that all of the beam energy or power could enter the eye. In this case, divide the laser output energy or power by the maximum area of the pupil (approximately 0.4 cm^2). This radiant exposure or irradiance may be used in table 4–1.

c. If the observer is in a fixed position and cannot receive the maximum output radiant exposure or irradiance, then a measured value may be used (e.g., downrange from laser beam).

APPENDIX G
FIRST AID PROCEDURES FOR INCLUSION IN LASER SOPs

G–1. First Aid Procedures for Electrical Shock Victims. *a.* Before touching a victim of electric shock, the circuit should be deenergized 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. Cardiopulmonary resuscitation (CPR) procedures appropriate to the victim's condition shall be started immediately.

b. First establish the unresponsiveness of the victim by tapping, gentle shaking, and shouting. Call out for help. If unresponsive, place your ear near the victims nose. Listen for breath sounds, feel for breathing on your cheek, and look for chest movement indicating breathing. If no breathing is apparent, position the patient as in paragraph *c* and give four short breaths by mouth to mouth ventiliation. Then palpate the neck for the carotid pulse. If no spontaneous breathing is present, begin mouth to mouth ventilation (para *c*). If no carotid pulse is present, begin external cardiac compression (para *d*).

c. Mouth-to-mouth resuscitation may be performed as follows:

(1) *Place the victim on his or her back.* Place on a firm surface such as the floor or ground, not on a bed or sofa.

(2) *Tilt the victim's head straight back.* Extend the neck up as far as possible. (This will automatically keep the tongue out of the airway.)

(3) *Open your mouth wide and place it tightly over the victim's mouth.* At the same time, pinch the victim's nostrils shut, or close the nostrils with your cheek, or close the victim's mouth and place your mouth over his or her nose.

(4) *Blow into the victim's mouth, or nose,* with a smooth steady action until the victim's chest is seen to rise.

(5) *Remove your mouth.* Allow the victim to exhale passively and watch the victim's chest fall.

(6) *Repeat.* This cycle should be continued at the rate of one breath each 5 seconds.

WARNING

If you are not getting an air exchange, quickly recheck the position of the head and the adequacy of the seal around the mouth. If attempts to ventilate are still unsuccessful, sweep your fingers through the victim's mouth and into his or her throat to remove any foreign bodies. If the rescuer is unable to dislodge the foreign body, turn the victim on his or her side and give several sharp blows between the shoulder blades to jar it free. After four quick breaths, stop and determine if the heart is beating by gently feeling the carotid pulse. If the heart is beating, return to the mouth.

d. External cardiac compression, if necessary, may be performed as follows:

(1) If the carotid pulse is absent or questionable, start artificial circulation by external cardiac compression.

(2) Place the heel of one hand on the lower one half of the breastbone and the other hand on top of the first.

(3) Thrust downward from your shoulders with enough force to depress the breastbone about 1½ to 2 inches.

(4) Relax immediately after each downstroke to permit natural expansion of the chest.

(5) Repeat at the rate of about one downstroke per second. The compressions must be regular, smooth, and uninterrupted. If you are alone with the victim, you must alternate mouth-to-mouth breathing with external cardiac compression at the ratio of about 2 to 15 (two breaths, then 15 heart compressions). If you have help, the ratio is five compressions to one inflation. Continue one or both of the above while the victim is being transported to the hospital, until patient revives, or until told to stop by a physician.

(6) Once the victim is breathing again, treat for physical shock if symptoms are present.

G–2. Treatment for Shock. If the patient is pale, cold, sweaty, weak and has a rapid pulse, treat by—

a. Laying the patient down.
b. Loosening the patient's clothes.
c. Keeping the patient warm.
d. Elevating the patient's legs.
e. Keeping the patient quiet.

G–3. First Aid for Eye Injury from Laser Energy. First aid should not be attempted for damage produced by laser energy to the eye; therefore, prompt reporting to a medical treatment facility is imperative for known or suspected laser injuries. Report injuries to Occupational Health Section, Bldg ____, during regular duty hours; during weekends, holidays and after regular duty hours report to walk-in clinic, XYZ Army Community Hospital, Bldg ____, for treatment. For ambulance service call ____. Telephone number for Occupational Health Section is ____.

G–4. First Aid for Eye Injury from Caustic Chemicals. A deluge type eye wash and/or shower shall be

GLOSSARY

Section I. ABBREVIATIONS

AEL	accessible emission limit
AIT	advanced individual training
ANSI	American National Standards Institute
CPR	cardiopulmonary resuscitation
CO_2	carbon dioxide
CW	continuous wave
EL	exposure limit
EEL	effective exposure limit
FM	field manual
GDL	gas dynamic laser
GTL	gas transport laser
Hz	Hertz
IR-A	infrared-"A"
IMA	installation medical authority
J	joule
km	kilometer
kV	kilovolt
LAIR	Letterman Army Institute of Research
LASER	light amplification by stimulated emission of radiation
LRF	laser rangefinder
LRSO/NCO	laser range safety officer/noncommissioned officer
LSDZ	laser safety danger zone
mm	millimeter(s) (1×10^{-3} meter(s))
ms	millisecond(s)
mW	milliwatt(s)
μm	micrometer(s) (1×10^{-6} meter(s))
NATO	North Atlantic Treaty Organization
nm	nanometer(s) (1×10^{-9} meter(s))
NOHD	nominal ocular hazard distance
OD	optical density
PRF	pulse repetition frequency
RDTE	research, development, testing, and evaluation
s	second(s)
SOP	standing operating procedure
sr	steradian
STANAG	international standarization agreement
TEM	transverse electromagnetic wave
TM	technical manual
UV	ultraviolet
USAEHA	US Army Environmental Hygiene Agency
W	watt(s)

Section II. TERMS

Accessible Emission Limit (AEL)
Maximum accessible emission level within a particular class.

Accommodation
Ability of the eye to change its power and thus focus for different object distances.

AEL for Class 1
That radiant power or energy of a laser under consideration such that no applicable exposure limit for exposure of the eye for a specified exposure duration can be exceeded under any possible viewing conditions with or without optical instruments, whether or not the beam is focused (app D).

Angstrom (A)
Unit of measure of wavelength equal to 10^{-10} meter, 0.1 nanometer, or 10^{-4} micrometer.

Irradiance (E)
Power per unit area on a given surface, in units of watts-per-square-centimeter ($W{\cdot}cm^{-2}$).

Joule (J)
A unit of energy (1 watt-second) used normally in describing a single pulsed output of a laser; it is equal to 1 watt-second or 0.239 calories.

Joule·cm^{-2} (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.

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

Laser
A source of intense, coherent and directional optical radiation. Also, an acronym for *light amplification by stimulated emission of radiation.* A laser usually is composed of an energy source, a resonant cavity, and an active lasing medium.

Laser Device
Either a laser or a laser system.

Laser Range Safety Officer/NCO (LRSO/NCO)
Direct representative of the individual in charge of laser operations; can be either a qualified civilian or military person.

Laser Safety Danger Zone (LSDZ)
The ground area that requires 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 System
An assembly of electrical, mechanical, and optical components that includes a laser.

Laser Controlled Area
Any area that contains one or more lasers and the activity of personnel is subject to control and supervision.

Light
Visible radiation (400 nm to 700–780 nm). For the purposes of this bulletin, limited to wavelengths between 400 and 700 nm.

Micrometer (μm)
Formerly termed *micron,* a measure of length equal to 10^{-6} m.

Nanometer (nm)
Unit of length equal to 10^{-9} m.

Nominal Ocular Hazard Distance (NOHD)
The NOHD is the distance from the operating laser at which the radiant exposure or irradiance within the beam equals the applicable exposure limit.

Ocular Surveillance Examination
A professional eye evaluation performed by an ophthalmologist, optometrist, or physician skilled in funduscopy and biomicroscopy of the eye.

Open Installation
Any location where lasers are used that will be open to operating personnel during laser operation, and may or may not specifically restrict entry to casuals.

Optical Density (OD)
A logarithmic expression for the attenuation produced by an attenuating medium, such as an eye protection filter.

$$OD\ \log_{10} OD = \log_{10} \Phi_o/\Phi_t$$

Where Φ_0 is the incident power and Φ_t is the transmitted power at a specific wavelength.

Optically Pumped Lasers
A type of laser that derives energy from another optical radiation source such as a xenon flash lamp (coherent light sources have also been used).

Point Source of Optical Radiation
Ideally, a source with infinitesimal dimensions. Practically, a source of radiation whose dimensions are small compared with the viewing distance. For this guide, a source which subtends an angle at the viewer less than minutes.

Pulse Duration
Duration of a pulsed laser flash; it may be measured in terms of milliseconds (ms = 10^{-3} s), microseconds (μsec = 10^{-6} s), or nanoseconds (ns = 10^{-9} s). The time interval between the half-peak-power points on the leading and trailing edges of the pulse.

Pulsed Laser
A laser that delivers its energy in short pulses, as distinct from a CW laser. For the purposes of this bulletin, a laser that emits for less than 0.25 s.

Quantum Mechanics
Branch of science dealing with atomic and subatomic particles.

Q-switched Laser
A laser capable of extremely high peak powers for very short durations (pulse duration of several nanoseconds). A laser with a pulse width between 1 ns and 18 μs.

Radian
A unit of angular measure equal to the angle subtended at the center of a circle by an arc whose length

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JOHN A. WICKHAM, JR.
General, United States Army
Chief of Staff

Official:

DONALD J. DELANDRO
Brigadier General, United States Army
The Adjutant General

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