LASER

SAFETY

PLAN

Review and Approval Authority

Prepared and Edited by:

_____	_____
Laser Safety Officer	Date

Reviewed and Approved by:

_____	_____
Director - Environmental Safety	Date
_____	_____
Director - University Health Center	Date
_____	_____
Associate Provost for Research and Dean of the Graduate School	Date
_____	_____
Provost	Date

Approved as UM Policy:

_____	_____
President	Date

On-site Laser Safety Plan Completed by:

_____		_____
Name	Title	Date

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Table of Contents

Tables

Executive Summary

The purpose of this plan is to provide guidance for the safe use of lasers. The American National Standard Institute recommends procedures and provides for such in ANSI Z.136.1, American National Standard for Safe Use of Lasers. This guide is based on the ANSI standard as well as recommendations made by the Occupational Safety and Health Administration (OSHA).

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UM Policy on Occupational Exposure to Laser Light

A. Purpose.

This is a statement of official University policy to establish the process for maintaining occupational exposures to laser light within acceptable industry standards, as recommended by the American National Standard for Safe Use of Lasers, (ANSI) Z-136 as well as the Occupational Safety and Health Administration (OSHA) Guidelines for Laser Safety and Hazard Assessment.

B. Policy.

The University is dedicated to providing safe and healthy laboratory facilities for students and employees. Laboratory administrators, managers, faculty, staff and students share responsibility for minimizing exposure to hazardous laser light, which for the purpose of this policy includes all laser light between 0.180 and 10.6 microns, inclusive.

The Laser Safety Plan (LSP) shall be implemented for all facilities at the University of Maryland at College Park (UM) where the referenced lasers are utilized for research, education and training, manufacturing, and other processes.

The LSP shall be reviewed on an annual basis and updated as necessary.

C. Responsibilities.

1. Department of Environmental Safety (DES) Shall:

(a) Provide a Laser Safety Officer (LSO) to develop and coordinate administration of the UM Laser Safety Plan (LSP);
(b) Prepare the LSP with annual review and revision;
(c) Distribute the LSP to each Laboratory Supervisor or Principal Investigator (LS/PI);
(d) Provide consultation, worksite monitoring, hazard analysis, and advisory assistance and information concerning the use of hazardous laser light;
(e) Investigate, document, and report any significant exposure to laser light to the Director of Environmental Safety, and Chair of the department in which the incident occurred;
(f) Direct periodic laboratory safety audits and recommend action to correct conditions generating the release of hazardous laser light;
(g) Provide initial training to all users of lasers based on the class of lasers in use. Refresher training shall be provided each year based on Occupational Safety & Health Administration (OSHA) recommendations; shall be commensurate with the operation and class of lasers in use; and as a minimum provide:
    (1) Provisions of the LSP;
    (2) Physical and health hazards of lasers in the area;
    (3) Measures to protect employees;
    (4) Signs associated with laser exposure;
    (5) References on hazards, and safety features regarding laser light;
    (6) OSHA recommendations and the ANSI standard;
(h) Establish a system of notification for purchases involving lasers or systems containing lasers.

2. Laboratory Supervisors/ Principal Investigators (LS/PI) shall:

(a) Implement all provisions of the LSP for laboratory facilities under their control;
(b) Prepare an inventory of lasers in laboratories under their control;
(c) Prepare laboratory specific Standard Operating Procedures (SOPs) which includes information provided in Appendix III;
(d) Train laboratory workers regarding the specific practices and provisions in the SOP; and
(e) Comply with necessary documentation requirements.
(f) Determine and implement medical surveillance requirements.

3. University Health Center Shall:

(a) Maintain medical records relating to consultations and examinations as required by law.

4. Individual Researchers and Laboratory Users shall:

(a) Adhere to the requirements of the LSP and SOPs;
(b) Complete all safety training requirements and comply with documentation procedures; and
(c) Report all workplace injuries, exposures, or unsafe conditions to the LS/PI as soon as possible.

D. Information.

Assistance will be provided by the DES to any department requesting guidance or training to satisfy implementation of this policy.

Emergency Telephone Numbers

UM Emergency (FIRE - POLICE - RESCUE) - 24 hour # 911

CALL IMMEDIATELY FOR ANY EMERGENCY INCLUDING INJURED OR SICK PERSON CHEMICAL SPILL OR FIRE

Environmental Safety (Main Office) . . . . . (40)5-3960
(Biosafety, Environmental Affairs, Occupational Safety and Health, Radiation Safety, Risk Management)

Laser Safety Officer . . . . . (40)5-3985
(Program Consultation and Administration)

Radiation Safety . . . . . (40)5-3985
(Health Physics, Radioactive Materials Procurement)

University Health Center Occupational Health . . . . . (31)4-8172
(Medical Consultation and Evaluation)

Workers' Compensation Office . . . . . (31)4-8171

Facilities Management Work Control . . . . . (40)5-2222
(Repair of Facility Equipment Deficiencies, e.g.,
fume hoods, emergency eyewashes, ventilation, etc.)

Laboratory Supervisor(s):	Business-hours #	After-hours #
_____	_____	_____
_____	_____	_____

Laboratory Personnel:	Business-hours #	After-hours #
_____	_____	_____
_____	_____	_____
_____	_____	_____

Standard Operating Procedures (SOPs)

A comprehensive health and safety program should include documents that provide descriptions of standard methods or operations used within the facility. They should describe in clear and precise language the means and methods to be used by laboratory workers to minimize the risk of hazardous exposure while using hazardous lasers. These documents, commonly referred to as standard operating procedures (SOPs), should be followed by all laboratory employees.

The LS/PI is responsible for preparation of the SOP documents for attachment to the LSP. The LS/PI is responsible for determining the adequacy of the SOPs prepared. The SOPs shall be incorporated in the on-site copy of the LSP and placed in a designated location within the laboratory for immediate access by employees.

A good SOP is one that is clearly stated and realistic in scope. A LS/PI should prepare SOPs for all routine and repetitive operations as well as for general laboratory operations. The format of all SOPs should be consistent and should incorporate:

1. Facility name, department and section affected by or using the procedure;

2. Subject;

3. Issue date of the original document or current revision;

4. Any indication that revisions replace an earlier procedure;

5. Signature or initials of the SOP preparer as well as any reviewing authority; and

6. Concise instructions for safe and healthful performance of laboratory activities and procedures.

SOPs should indicate the measures that will be used to reduce or prevent employee exposure to hazardous laser light, including engineering controls, and the use and maintenance of personal protective equipment.

SOPs should include provisions for additional employee protection for work with particularly hazardous substances, including electrical connections, and high pressure gas vessel use.

SOPs should also indicate circumstances under which certain laboratory procedures, operations, or activities require prior approval from the LS/PI before implementation (e.g. use of radioactive materials, bench top manipulations without engineering controls, night or weekend work performed alone, etc...)

An outline for SOPs or lasers may be found in Appendix III.

Medical Surveillance

Laser radiation has been shown to cause damage to the eyes. Medical Surveillance will serve to:

(1) establish a baseline against which damage can be measured;

(2) identify workers which might be at special risk from chronic exposure to certain CW lasers.

Medical surveillance is recommended by current standards of practice and may be required by some research funding agencies for personnel using class IIIB and IV lasers. The LS/PI must determine whether their research project requires medical surveillance.

Personnel Categories

Incidental Personnel

Those personnel whose work make it unlikely to be exposed to laser energy sufficient to damage eyes or skin, such as clerical and custodial workers.

Those personnel who work routinely within a laser environment, and are protected by engineering, procedural, and administrative controls.

Frequency of Medical Exams

Required examinations for both categories of personnel shall be performed prior to participation in laser work. In the case of a suspected laser injury, the examination shall be repeated. Periodic examinations are not required.

Termination Medical Examinations

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

Cost of medical surveillance examinations are the responsibility of the researcher's department. The cost of emergency medical examinations is covered by worker's compensation insurance or an individual's health care insurance.

Emergency Medical Consultation and Examinations

Employees who work with hazardous lasers in the laboratory should be referred for medical consultation, examination, and/or surveillance (as appropriate to the circumstances) whenever:

1. An employee develops signs or symptoms associated with hazardous exposure to laser light;

2. An event takes place in the work area to create a likelihood of hazardous exposures; or

3. Exposure monitoring reveals an exposure level routinely above the action level (or in the absence of an action level, the Maximum Permissible Exposure limit);

Examples of events or circumstances which might result in hazardous exposure include:

1. Direct eye or skin contact with laser light;

2. Symptoms such as headache, rash, nausea, tearing, irradiation or redness of eyes, or irritation of skin;

3. Two or more employees in the same laboratory with similar symptoms; or

4. Exposure monitoring indicates exposure above recommended limits.

The University has established procedures for responding to job-related injuries. These procedures should be followed in the event of hazardous exposure due to the use of hazardous lasers in the laboratory (See page 18). In the event of life threatening injuries or illnesses, the UM Emergency Dispatcher should be immediately notified by calling 9-1-1. Any injury or illness occurring as a result of work activities should be reported to the Workers' Compensation Office, immediately after the incident occurs or the injury is treated. All incidents of hazardous exposure, including their disposition, should be reported to the Laser Safety Officer.

The following information should be provided at the time that an employee is referred for medical consultation and/or examination:

1. Identity of the laser(s) to which the employee may have been exposed;

2. Description of the conditions under which the exposure occurred, including quantitative exposure data, if available; and

3. A description of the signs and symptoms of exposure that the employee experienced, if any.

A written report must be provided to the employer from a physician to whom the employee is referred for medical consultation or examination connected with hazardous exposure. The physicians's report(s) should indicate ONLY the specific findings of diagnoses related to occupational exposure and should include the following information:

1. Any recommendation for further medical follow-up;

2. The results of the medical examination and any associated test(s);

3. Any medical conditions which may be revealed in the course of the examination which may place the employee at increased risk as a result of exposure to a hazardous workplace; and

4. A statement that the employee has been informed by the physician or the results of the consultation or medical examination and any medical condition that may require further examination or treatment.

As indicated above, all incidents of hazardous exposure (including disposition) should be reported to, and documented by, the Laser Safety Officer (LSO). If no further assessment of the incident is deemed necessary, the reason for that decision should be included in the documentation. If the event is determined to require investigation, a formal exposure assessment will be initiated by the LSO.

The purpose of an exposure assessment is not to determine whether there was a failure to follow proper procedures, but to identify the hazardous laser light involved and determine whether an exposure might have caused harm to an employee. An exposure assessment may include the following items:

1. Interviews with the employee and complainant (if different);

2. Obtaining the following information:
   - type of lasers involved
   - other lasers used by employee
   - all lasers used by others in the immediate area
   - symptoms exhibited or claimed by the employee
   - comparison of symptoms with those referenced by OSHA
   - observation of control measures and personal protective equipment in use

during the event
- notation of any on-site exposure monitoring performed previous to or during event

3. Determination of whether the current control measures were adequate during the time of the incident.

Information and Training

All UM employees must assume an active role in maintaining a safe working environment by reporting any problems or noncompliance with policies to the LS/PI. All employees should fully utilize any information provided during formal and informal training sessions. Any staff member who does not understand a policy or procedure should consult the LS/PI, or DES for clarification.

All employees should be provided with information and training regarding the hazards of the lasers in their work area. Employees should be informed of:

1. Contents of the OSHA guidelines and its appendices;

2. Location and availability of the LSP;

3. Maximum Permissible Exposure Limits (MPEs) for ANSI standards and any recommended exposure limits for OSHA;

4. Methods and observations used to detect the presence or release of laser light;

5. Physical and health hazards of lasers in the work area;

6. Measures employees can take to protect themselves from laser light including specific procedures (SOPs) to be used;

7. Signs and symptoms associated with exposures to hazardous laser light used int the laboratory;

8. The location of known reference material on the hazards, safe handling, storage, and disposal of lasers found in the laboratory.

Distribution of training materials to LS/PIs is coordinated through the DES. Training of laboratory workers in the guidelines of OSHA recommendations and ANSI standards should be conducted through coordination with the LSO, and DES. The LS/PI is responsible for training all laboratory workers on the specific operations, safety features, emergency procedures and SOPs which apply to their facility and laser(s) in use. Documentation of training must be maintained by the LS/PI in each department, and original copies of training certificates provided to the LSO.

Engineering Controls

Lasers which are purchased from a commercial manufacturer must meet the requirements of the Federal Laser Product Performance Standard (FLPPS). This regulation mandates that the manufacturer must supply certain engineering controls to the laser system. Homemade lasers will be classified in accordance with ANSI (no different than manufactured lasers). The following controls are supplied by the manufacturer:

1. Protective housing, **(all classes);**

2. Non-Protective housing use, **(all classes);**
   Some areas of research result in the use of lasers without protective housing. In this case a hazard analysis should be effected and appropriate control measures instituted. Areas of analysis should include:
   (a) access restrictions;
   (b) eye protection;
   (c) area controls;
   (d) barriers, shrouds, beam stops;
   (e) administrative and procedural controls;
   (f) education and training.

3. Interlocks on removable protective housing, **(all classes);**
   (a) class IIIB and IV lasers shall be provided with an interlock that is activated when the housing is opened during operation or maintenance;
   (b) failsafe interlocks shall be provided for any portion of the housing that may provide access to IIIB or IV type lasers;

4. Service access panels, **(all classes);**
   If direct access is permitted to class IIIB or IV lasers then a tool for removal of the housing shall be required with appropriate warning signs and labels;
   (a) the access panel shall be interlocked;

5. Key control, **(class IIIB and IV);**
   Class IV lasers shall have a master switch operated by a key or coded access with master switch disabled when the system is not in use; The electrical input terminus shall be designed to allow lockout/tagout procedures as required by OSHA 1910.147;

6. Viewing portals and display screens, **(class II, IIIA, IIIB, & IV);**
   Maintain the level of laser light below the MPE through use of

shutters, interlocks or filters;

7. Remote interlock connector, **(class IIIB and IV);**
   Class IV shall have such a connector;

8. Beam stop or attenuator, **(class IIIB and IV);**

   Class IV shall be provided with a permanently attached attenuator;

9. Laser activation warning system, **(class IIIB and IV);**
   Class IV systems shall have an audible, bell, chime, etc... during activation or startup;

10. Emission delay, **(class IV);**
    The delay shall be sounded a suitable time prior to laser light emission;

11. Equipment labels, **(all classes);**
    Shall have appropriate warning labels with the laser sunburst symbol and cautionary statement affixed to the housing or control panel;

Laser Controlled Areas

A laser controlled area should be established when a hazard analysis determines the laser to be either a class IIIB or class IV. The following recommendations should be included with a class IIIB or IV controlled area:

Class IIIB laser controlled area guidelines:

(1) Posting with appropriate warning signs at the entryway(s);
(2) Only trained operators use the system;
(3) Limit the beam path;
(4) Limit access;
(5) Use beam stops;
(6) Have only diffuse reflected material near the beam;
(7) Provide personnel with appropriate eye protection;
(8) Have beam path at height other than eye level;
(9) Disable the system when not in use;

Class IV laser controlled area guidelines, in addition to class IIIB controls the following guidelines pertaining to a class IV system:

(1) Follow appropriate SOPs;
(2) Be appropriately trained;
(3) Have a designated rapid egress;
(4) Clearly mark " Panic Button";
(5) Incorporate non-defeatable, defeatable, or procedural area and entryway controls, to prevent an exposure in the case of an inadvertent entry.

Protective Eyewear

Protective eyewear is required when a class IIIB or IV laser is used.

Selecting appropriate eyewear: The following factors should be taken into account when selecting the appropriate eyewear:

- Wavelength
- Tunability
- Worst case radiant exposure or irradiance level
- MPE
- Optical density
- Angular dependence
- Visible light transmission
- Peripheral vision/protection
- Comfort and fit
- Photobleaching
- Anti-fogging

The equation for optical density is as follows:

$$OD = \log_{10} [H_o / MPE]$$

where H_o = anticipated worst case exposure; expressed in units of W/cm^2 for CW sources, and in units of J/cm^2 for pulsed sources.

MPE = maximum permissible exposure in identical units to H_o.

Values for MPE are found in Table 1.

Selected optical densities for some typical lasers may be found in Table 7.

Warning Labels and Signs

Signs and labels need to comply with acceptable standards. The LSO will recommend and supply labels and signs to the LS/PI for their facility.

Doors must be placarded in the case of Class IIIB and IV lasers.

Non-Beam Hazards

Electrical hazards:

Electrical hazards are present with high voltage systems which power lasers. Electric shock is a serious hazard which can be fatal.

The primary protection against accidental contact with energized conductors is by means of a barrier system.

Electrical safety requirements may be found in OSHA National Electric Code, NFPA 70.

The DES Lockout/Tagout (LOTO) Plan establishes a policy for control of hazardous energy. All employees of the University and contract workers servicing equipment that can be energized must comply with this plan. The LOTO Plan is available from DES and may be obtained by calling (40)5-3960.

Laser Generated Air Contaminants (LGACS):

The LS/PI should consider the possible exposure to LGACs. These may include but are not limited to:

(a) metallic fumes and dusts;
(b) metallic oxide fumes;
(c) chemical and gaseous vapors;
(d) biological fragments from human and animal tissue;
(e) bio-aerosols;
(f) hydrocarbons;
(g) heavy metals;
(h) synthetic and natural fibers;

Exposure criteria may be found in 29 CFR 1910 part Z as well as threshold limit values for chemical substances by the ACGIH. Additional information may be found by consulting Material Safety Data Sheets.

Other considerations include the need for:

(a) Respiratory protection;
(b) Fire protection;
(c) Exhaust ventilation;
(d) Collateral and X-ray radiations;
(e) Laser dye use;
(f) Noise protection.

The DES Occupational Safety and Health (OSH) section investigates potential xposures to air contaminants. Where there is a potential for the generation of LGACS, the employee shall call DES for information and assistance at (40)5-3960

Laser Safety References

Recommended reference sources concerning safety operations with lasers include:

Safety with Lasers and Other Optical Sources
Plenum Press

American National Standard for Safe Use of Lasers
Laser Institute of America

OSHA Instruction PUB 8 - 1.7
OSHA

Journal of Laser Applications
Chapman and Hill

APPENDIX I
Emergency Evacuation Procedures

IN CASE OF FIRE OR EMERGENCY:

1. Pull the fire alarm;

2. Leave the building; and

3. Call 9-1-1.

The fire alarm is NOT connected to the fire department.

Notify (40)5-2222 IMMEDIATELY for service or repair to fire protection systems.

A current copy of the UM Policy Concerning Fire Emergencies can be found on the UM Mainframe (INFORM). From the main menu select Campus Information; then select Departments and Services; then select Environmental Safety; then select UM Policy Concerning Fire Procedures.

APPENDIX II
UM Workers' Compensation Reporting Procedure

In case of an accident or incident involving laser light, the individual should report immediately to the Health Center for medical treatment.

Worker-related injury and illness forms and information are distributed by the medical records personnel when the individual reports to the Health Center**.**

APPENDIX III
Outline for Standard Operating Procedures

1. Introduction
   - (a) Location of laser (site, building, room);
   - (b) Diagram of room layout;
   - (c) Description of each laser, including classification, lasing medium, beam characteristics, divergence, aperture diameter, pulse length, repetition rate, and maximum output;
   - (d) Application of the beam;

2. Hazards
   - (a) Identify beam and non-beam hazards;
   - (b) Analysis and Control;

3. Controls
   - (a) Access controls such as door interlocks, signs, etc...;
   - (b) Beam controls such as key-lock, enclosures, shutters, etc...;
   - (c) Electrical controls on High Voltage, "light on" power supply;
   - (d) Eye protection such as Medical Surveillance Requirement, types of eyewear, optical density for beam(s);
   - (e) Other controls as needed;

4. Operating Procedures
   - (a) Initial preparation of laboratory for normal operation such as key position, warning lights on, interlock(s) activated, identification of all personnel present;
   - (b) Personnel protection requirements acknowledged by persons present;
   - (c) Target area;
   - (d) Countdown procedure;
   - (e) Shutdown procedure;
   - (f) Special procedures such as emergency, alignment, etc...;

5. Training

(a) Department of Environmental Safety Training;
(b) Specific training, OJT on laser in use;
(c) Maintenance and repair training if applicable;

6. Responsibilities
   (a) Supervisor for normal operations;
   (b) Emergency coordinator;
   (c) Operators and other personnel;

7. Miscellaneous
   (a) Visitor regulations at site;
   (b) Accident procedures;
   (c) Other as applicable.

APPENDIX IV
Laser Inventory Reporting Procedure

Both the LS/PI and the Department of Environmental Safety will maintain records of lasers. Inventory of lasers may be coordinated with the LSO. Information that should be supplied in order to track lasers includes but is not limited to:

1. Manufacturer;
2. Model number;
3. Serial number;
4. Location, room, etc...;
5. Type, such as CW or pulsed or Repetitively pulsed;
6. Wavelength;
7. Average Power;
8. Exposure time;
9. Energy/pulse;
10. Pulse duration;
11. Frequency (Hz) or repetition;

APPENDIX V
Laser Classification Scheme

The American National Standard for Safe Use of Lasers, ANSI Z136.1, Occupational Health and Safety Administration (OSHA), Instruction PUB 8-1.7, and the Center for Devices and Radiological Health (CDRH), through the Federal Laser Product Performance Standard, 29 CFR Part 100 classify lasers according to accessible radiation.

Classification relates to the potential for the laser beam to cause injury and not from any ancillary hazards that may be present with the laser system.

ANSI, OSHA, and the CDRH classifications vary according to the class of laser. The following classifications are a general outline incorporating all 3 schemes. Specifics on the classifications may be found by referencing the standards and the regulations. These are available from the Department of Environmental Safety and the LSO.

Class I:

1. Usually in the visible region;
2. Not considered hazardous;
3. Exempt from controls;
4. In some cases a higher class, such as IIIB or IV, is enclosed and is classified as a class I, however during times of service or maintenance the classification may change to reflect the exposure to the class IIIB or IV;

Class II:

1. Visible lasers emitting above the class I level of power;
2. Output power less than 1 mW;
3. May produce an injury if stared at for longer than the aversion response time of 0.25 seconds, called a chronic viewing hazard;
4. Will not produce a skin burn;

Class IIA:

1. Not for continuous viewing longer than 1000 seconds;
2. Visible light which can produce greater than class I power;

Class IIIA:

1. Can be an acute intrabeam viewing or chronic viewing hazard;
2. Power level less than 5 mW CW;
3. Can be invisible (ANSI) or visible (CDRH);

Class IIIB:

1. Acute hazard to skin and eye from the direct beam;
2. Visible or invisible;
3. Power level less than 500 mW CW, 10 J/cm^2 pulsed;
4. Diffuse reflections may be a hazard if operation is at full power and viewing is close to the source of reflection;

Class IV:

1. Acute hazard to skin and eye from direct and scattered light;
2. Power levels exceed class IIIB levels;
3. Fire hazard.

Specific classification tables for lasers may be found in the Appendix. CDRH classification may be found on the laser itself when purchased.

APPENDIX VI
Maximum Permissible Exposures

MAXIMUM PERMISSIBLE EXPOSURE (MPE)

The level of laser radiation to which a person may be exposed without the hazardous effect or adverse biological changes in the eye or skin.

MPE values are determined for the eye (intrabeam), for an extended source, and for the skin.

ACCESSIBLE EMISSION LIMIT (AEL)

The Maximum Accessible Emission level permitted within a particular class.

AEL = MPE x (Area of Limiting Aperture)

EXPOSURE DURATIONS

Exposure duration times are used when determining the MPE levels for a laser hazard. The exposure durations are based on physiological and biological response times to exposures from sources of light in the case of the eye, and heat in the case of skin response.

TIME (SEC)	EXPLANATION
3×10^4	Occupational 8 hour work day.
86,400	Accumulate "ON" time for ultraviolet wavelengths over 24 hour period.
600	Visible wavelengths used for alignment.
10	For normal maximum exposure time, infrared wavelengths due to natural body movements.
0.25	Normal eye aversion response to bright visible light.

TABLE 1
Maximum Permissible Exposure (MPE) for Ocular Exposure (Intrabeam Viewing) to a Laser Beam

Wavelength (μm)	Exposure Duration, t (s)	MPE ($J \cdot cm^{-2}$)	MPE ($W \cdot cm^{-2}$)	Notes
Ultraviolet				
0.180 to 0.302	10^{-9} to 3×10^{4}	3×10^{-3}		
0.303	10^{-9} to 3×10^{4}	4×10^{-3}		
0.304	10^{-9} to 3×10^{4}	6×10^{-3}		
0.305	10^{-9} to 3×10^{4}	10×10^{-3}		
0.306	10^{-9} to 3×10^{4}	16×10^{-3}		or $0.56\,t^{1/4}$,
0.307	10^{-9} to 3×10^{4}	25×10^{-3}		whichever is lower.
0.308	10^{-9} to 3×10^{4}	40×10^{-3}		
0.309	10^{-9} to 3×10^{4}	63×10^{-3}		
0.310	10^{-9} to 3×10^{4}	0.1		(See Tables 8 and 9
0.311	10^{-9} to 3×10^{4}	0.16		for limiting apertures)
0.312	10^{-9} to 3×10^{4}	0.25		
0.313	10^{-9} to 3×10^{4}	0.40		
0.314	10^{-9} to 3×10^{4}	0.63		
0.315 to 0.400	10^{-9} to 10	$0.56\,t^{1/4}$		
0.315 to 0.400	10 to 3×10^{4}	1.0		
Visible and Near Infrared				
0.400 to 0.700	10^{-9} to 18×10^{-6}	0.5×10^{-6} †		
0.400 to 0.700	18×10^{-6} to 10	$1.8\,t^{3/4} \times 10^{-3}$ †		
0.400 to 0.550	10 to 10^{4}	10×10^{-3} †		
0.550 to 0.700	10 to T_1	$1.8\,t^{3/4} \times 10^{-3}$ †		
0.550 to 0.700	T_1 to 10^{4}	$10\,C_B \times 10^{-3}$ †		
0.400 to 0.700	10^{4} to 3×10^{4}		$C_B \times 10^{-6}$ †	(See Tables 8 and 9
0.700 to 1.050	10^{-9} to 18×10^{-6}	$0.5\,C_A \times 10^{-6}$		for limiting apertures)
0.700 to 1.050	18×10^{-6} to 10^{3}	$1.8\,C_A\,t^{3/4} \times 10^{-3}$		For multiple pulses
0.700 to 1.050	10^{3} to 3×10^{4}		$320\,C_A \times 10^{-6}$	apply correction factor C_P
1.050 to 1.400	10^{-9} to 50×10^{-6}	$5\,C_C \times 10^{-6}$		given in Table 6.
1.050 to 1.400	50×10^{-6} to 10^{3}	$9.0\,C_C\,t^{3/4} \times 10^{-3}$		
1.050 to 1.400	10^{3} to 3×10^{4}		$1.6\,C_C \times 10^{-3}$	
Far Infrared				
1.400 to 1.500	10^{-9} to 10^{-3}	0.1		
1.400 to 1.500	10^{-3} to 10	$0.56\,t^{1/4}$		
1.400 to 1.500	10 to 3×10^{4}		0.1	
1.500 to 1.800	10^{-9} to 10	1.0		(See Tables 8 and 9
1.500 to 1.800	10 to 3×10^{4}		0.1	for limiting apertures)
1.800 to 2.600	10^{-9} to 10^{-3}	0.1		For multiple pulses
1.800 to 2.600	10^{-3} to 10	$0.56\,t^{1/4}$		apply correction factor C_P
1.800 to 2.600	10 to 3×10^{4}		0.1	given in Table 6.
2.600 to 10^{3}	10^{-9} to 10^{-7}	10×10^{-3}		
2.600 to 10^{3}	10^{-7} to 10	$0.56\,t^{1/4}$		
2.600 to 10^{3}	10 to 3×10^{4}		0.1	

† The MPE for diffuse reflections at wavelengths between 0.400 and 1.400 μm is obtained by multiplying the corresponding MPEs above by C_E. (See Table 6 and Figure 9 for correction factors and T_1.)

Notes: 1. For repeated (pulsed) exposures, see 8.2.2.

2. The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$, e.g., 0.180 to 0.302 μm means $0.180 \leq \lambda < 0.302$ μm.

From ANSI Z136.1 (1993) Safe Use of Lasers, for complete information on laser safety, refer to the ANSI Z136 series of laser safety standards, contact Laser Institute of America at 1-800-34LASER for additional information.

TABLE 2
Parameters and Correction Factors

Correction Factor	Wavelength (μm)	Figure*
$T_1 = 10 \times 10^{30\,(\lambda - 0.550)}$	0.550 to 0.700	9
$C_B = 1.0$	0.400 to 0.550	9
$C_B = 10^{15\,(\lambda - 0.550)}$	0.550 to 0.700	9
$C_A = 1.0$	0.400 to 0.700	8a
$C_A = 10^{2\,(\lambda - 0.700)}$	0.700 to 1.050	8a
$C_A = 5.0$	1.050 to 1.400	8a
$C_P = n^{-1/4}$ **	0.400 to 1000	13
$C_E = 1.0 \quad \alpha < \alpha_{min}$	0.400 to 1.400	-
$C_E = \alpha / \alpha_{min} \quad \alpha_{min} < \alpha < \alpha_{max}$	0.400 to 1.400	-
$C_E = \alpha^2 / (\alpha_{max}\, \alpha_{min}) \quad \alpha > \alpha_{max}$	0.400 to 1.400	-
$C_C = 1.0$	1.050 to 1.150	8b
$C_C = 10^{18\,(\lambda - 1.150)}$	1.150 to 1.200	8b
$C_C = 8$	1.200 to 1.400	8b

* See figures for graphic representation.

** For pulse repetition frequencies below 55 kHz (0.4 to 1.05 μm) and below 20 kHz (1.05 to 1.4 μm). (See 8.2.2.2.)

Notes: 1. For wavelengths between 0.400 and 1.400 μm :

$\alpha_{min} = 1.5$ mrad for $t \leq 0.7$ s
$\alpha_{min} = 2\, t^{3/4}$ mrad for $0.7\ s < t < 10\ s$
$\alpha_{min} = 11$ mrad for $t \geq 10$ s
$\alpha_{max} = 100$ mrad

(See Figure 3 for graphical representation of α_{min}.)

2. The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$. e.g., 0.550 to 0.700 μm means $0.550 \leq \lambda < 0.700$ μm.

From ANSI Z136.1 (1993) Safe Use of Lasers, for complete information on laser safety, refer to the ANSI Z136 series of laser safety standards, contact Laser Institute of America at 1-800-34LASER for additional information.

TABLE 3
Limiting Apertures for Hazard Evaluation and AEL Determination

Spectral Region (μm)	Duration (s)	Aperture Diameter (mm) Eye	Skin
0.180 to 0.400	10^{-9} to 0.25	1.0	3.5
	0.25 to 3×10^{4}	3.5	3.5
0.400 to 1.400	10^{-9} to 3×10^{4}	7.0	3.5
1.400 to 10^{2}	10^{-9} to 0.3	1.0	3.5
	0.3 to 10 *	$1.5\ t^{3/8}$	3.5
	10 to 3×10^{4}	3.5	3.5
10^{2} to 10^{3}	10^{-9} to 3×10^{4}	11.0	11.0

* Under normal conditions these exposure durations would not be used for hazard evaluation.

Note: The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$ μm, e.g., 0.315 to 0.400 μm means $0.315 \leq \lambda < 0.400$ μm.

From ANSI Z136.1 (1993) Safe Use of Lasers, for complete information on laser safety, refer to the ANSI Z136 series of laser safety standards, contact Laser Institute of America at 1-800-34LASER for additional information.

TABLE 4
Measurement Apertures for Classification

Spectral Region (μm)	Duration (s)	Aperture Diameter (mm)
0.180 - 0.302	10^{-9} to 0.25	1.0
	0.25 to 3×10^{4}	3.5
0.302 - 2.8	10^{-9} to 3×10^{4}	50.0 **
2.8 - 10^{2}	10^{-9} to 0.3	1.0
	0.3 to 10 ***	$1.5\ t^{3/8}$
	10 to 3×10^{4}	3.5
10^{2} - 10^{3}	10^{-9} to 3×10^{4}	11.0

* These apertures are used for the measurement of optical power or energy for purposes of laser classification (see 3.3).

** When the laser output is intended to be viewed with optics (excluding ordinary eyeglasses) or the Laser Safety Officer determines that there is a reasonable probability of accidental viewing with optics, a 50 mm aperture is used if the following conditions are met:

(1) Viewing with optics presents a more severe hazard than unaided viewing.

(2) The viewing time is sufficient to constitute a hazard.

Otherwise, the limiting apertures for the eye and skin from Table 8 apply. For the specific case of optical viewing with beam collecting instruments, the apertures listed in Table 8 for hazard evaluation apply to the exit beam of the optical instrument. Therefore, the effective measurement aperture for UV lasers (0.302 to 0.400 μm) and some infrared lasers (1.4 to 2.8 μm) is 7 mm for pulsed lasers and 25 mm for CW lasers.

*** Under normal conditions, these exposure durations would not be used for classification.

Note: The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$ μm, e.g., 0.315 to 0.400 μm means $0.315 \leq \lambda < 0.400$ μm.

From ANSI Z136.1 (1993) Safe Use of Lasers, for complete information on laser safety, refer to the ANSI Z136 series of laser safety standards, contact Laser Institute of America at 1-800-34LASER for additional information.

TABLE 5
Accessible Emission Limits for Continuous-Wave Lasers and Laser Systems

Wavelength Range (μm)	Emission Duration (s)	Class 1† (W)	Class 2‡ (W)	Class 3§ (W)	Class 4 (W)
Ultraviolet					
0.18 to 0.302	3×10^4	$\leq 9.6 \times 10^{-9}$	—	> Class 1 but ≤ 0.5	> 0.5
0.302 to 0.4	3×10^4	$\leq 3.2 \times 10^{-8}$ depending on wavelength (see Table 5)	—	depending on wavelength (see Table 5)	> 0.5
Visible					
0.4 to 0.7	3×10^4	$\leq 0.4\, C_B \times 10^{-6}$ (see Table 5)	> Class 1 but ≤ 1×10^{-3}	> Class 2 but ≤ 0.5	> 0.5
Near Infrared					
0.7 to 1.05	3×10^4	$\leq 128\, C_A \times 10^{-6}$ depending on wavelength (see Table 5)	—	> Class 1 but ≤ 0.5 depending on wavelength (see Fig. 8)	> 0.5
	$10^{††}$	$\leq 3.9 \times 10^{-4}$ to $\leq 1.9 \times 10^{-3}$	—	> Class 1 but ≤ 0.5	> 0.5
1.05 to 1.4	> 1000	$\leq 600\, C_C \times 10^{-6}$ (see Table 5)	—	> Class 1 but ≤ 0.5	> 0.5
	10	$\leq 1.9 \times 10^{-3}$ to $\leq 1.6 \times 10^{-2}$	—	> Class 1 but ≤ 0.5	> 0.5
Far Infrared					
1.4 to 4	> 10	$\leq 9.6 \times 10^{-3}$	—	> Class 1 but ≤ 0.5	> 0.5
Submillimeter					
4 to 10^2	> 10	$\leq 9.6 \times 10^{-3}$	—	> Class 1 but ≤ 0.5	> 0.5
10^2 to 10^3	> 10	$\leq 9.5 \times 10^{-2}$	—	> Class 1 but ≤ 0.5	> 0.5

* Emission duration ≥ 0.25 s.

† When the design or intended use of the laser or laser system ensures personnel exposures of less than 10^4 s in any 24-hour period, the limiting exposure duration may establish a higher exempt power level, as discussed in 3.2.3.

‡ See 3.3.2.1 for explanation of Class 2a laser.

§ For 1 to 5 mW cw laser systems (Class 3a) see 3.3.3.1 and 3.3.3.2.

†† For laser not intended to be viewed.

Note: The wavelength range λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$, e.g., 0.18 to 0.4 μm means $0.18 \leq \lambda < 0.4$ μm.

From ANSI Z136.1 (1993) Safe Use of Lasers, for complete information on laser safety, refer to the ANSI Z136 series of laser safety standards, contact Laser Institute of America at 1-800-34LASER for additional information.

TABLE 6
Accessible Emission Levels (Radiant Energy) for Single-Pulsed Laser and Laser System Classification

Wavelength Range (μm)	Emission Duration ** (s)	Class 1 (J)	Class 3b (J)	Class 4 (J)
Ultraviolet				
0.18 to 0.302†	10^{-9} to 0.25	$\leq 1.9\times10^{-6}$	> Class 1 but ≤ 0.125	> 0.125
0.302 to 0.4	10^{-9} to 0.25	$\leq 1.9 \times 10^{-6}$	> Class 1 but ≤ 0.125	> 0.125
		$\leq 2.5\times10^{-4}$	> Class 1 but ≤ 0.125	> 0.125
Visible				
0.4 to 0.7	10^{-9} to 0.25	$\leq 0.2 \times 10^{-6}$	> Class 1 but ≤ 0.03	> 0.03
		$\leq 0.25 \times 10^{-3}$	> Class 1 but ≤ 0.03	> 0.03
Near Infrared				
0.7 to 1.05	10^{-9} to 0.25	$\leq 0.2 \times 10^{-6}$ to 2×10^{-6}	> Class 1 but ≤ 0.03 C_A	> 0.03 C_A
		$\leq 0.25 \times 10^{-3}$ to 1.25×10^{-3}	> Class 1 but ≤ 0.03 C_A	> 0.03 C_A
1.05 to 1.4	10^{-9} to 0.25	$\leq 2 \times 10^{-6}$	> Class 1 but ≤ 0.15	> 0.15
		$\leq 1.25 \times 10^{-3}$	> Class 1 but ≤ 0.15	> 0.15
Far Infrared				
1.4 to 10^3	10^{-9} to 0.25	$\leq 80 \times 10^{-6}$	> Class 1 but ≤ 0.125	> 0.125
		$\leq 3.2 \times 10^{-3}$	> Class 1 but ≤ 0.125	> 0.125
Submillimeter				
10^3 to 10^5	10^{-9} to 0.25	$\leq 10 \times 10^{-3}$	> Class 1 but ≤ 0.125	> 0.125
		≤ 0.4	> Class 1 but ≤ 0.125	> 0.125

* There are no Class 2 single-pulsed lasers.

** See Note in Section 8 for pulse widths less than 1 ns.

† Wavelength dependent (see Table 5).

Note: The wavelength range λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$, e.g., 0.18 to 0.4 μm means $0.18 \leq \lambda < 0.4$ μm.

From ANSI Z136.1 (1993) Safe Use of Lasers, for complete information on laser safety, refer to the ANSI Z136 series of laser safety standards, contact Laser Institute of America at 1-800-34LASER for additional information.

TABLE 6A
Typical Laser Classification
Continuous-Wave (CW) Lasers

Wavelength (μm)	Laser Type	Wavelength (μm)	Class 1 * (W)	Class 2 (W)	Class 3b ** (W)	Class 4 (W)
Ultraviolet						
0.180 to 0.280	Neodymium:YAG (Quadrupled)	0.266 only	$\leq 9.6 \times 10^{-9}$	—	> Class 1 but ≤ 0.5	> 0.5
	Argon	0.275	for 8 hours			
Ultraviolet						
0.315 to 0.400	Helium-Cadmium	0.325 only	$\leq 3.2 \times 10^{-4}$	—	> Class 1 but ≤ 0.5	> 0.5
	Argon	0.351, 0.363 only				
	Krypton	0.3507, 0.3564 only				
Visible						
0.400 to 0.700	Helium-Cadmium	0.4416 only	$\leq 0.4 \times 10^{-6}$	> Class 1 but $\leq 1 \times 10^{-3}$	> Class 1 but ≤ 0.5	> 0.5
	Argon (Visible)	0.457, 0.476, 0.488, 0.514, etc				
	Krypton	0.530				
	Neodymium:YAG (Doubled)	0.532				
	Helium-Neon	0.543				
	Dye	0.400 - 0.550				
	Helium-Selenium	0.460 - 0.550				
	Helium-Neon	0.632	$\leq 7 \times 10^{-6}$			
	Dye	0.550 - 0.700	$\leq 0.4 \times 10^{-6} - 7 \times 10^{-3}$			
	InGaAlP	0.670	$\leq 2.4 \times 10^{-3}$			
	Ti:Sapphire	0.670	$\leq 2.4 \times 10^{-3}$			
	Krypton	0.6471, 0.6764	$\leq 1.1 \times 10^{-3}, 3 \times 10^{-3}$			
Near Infrared						
0.700 to 1.400	GaAlAs	0.780	$\leq 0.18 \times 10^{-3}$	—	> Class 1 but ≤ 0.5	> 0.5
	GaAlAs	0.850	$\leq 0.25 \times 10^{-3}$			
	GaAs	0.905	$\leq 0.32 \times 10^{-3}$			
	Neodymium:YAG	1.064	$\leq 0.64 \times 10^{-3}$			
	Helium-Neon	1.080, 1.152 only	$\leq 0.64 \times 10^{-3}$			
	InGaAsP	1.310	$\leq 4.40 \times 10^{-3}$			
Far Infrared						
1.400 to 10^3	InGaAsP	1.550	$\leq 9.6 \times 10^{-3}$	—	> Class 1 but ≤ 0.5	> 0.5
	Holmium	2.100				
	Erbium	2.940				
	Hydrogen Fluoride	2.600 - 3.000				
	Helium-Neon	3.390 only				
	Carbon Monoxide	5.000 - 5.500				
	Carbon Dioxide	10.6				
	Water Vapor	118				
	Hydrogen Cyanide	337	$\leq 9.5 \times 10^{-2}$			

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

** See 3.3.3 for definition of Class 3a.

From ANSI Z136.1 (1993) Safe Use of Lasers, for complete information on laser safety, refer to the ANSI Z136 series of laser safety standards, contact Laser Institute of America at 1-800-34LASER for additional information.

TABLE 6B
Typical Laser Classification
Single-Pulse Lasers

Wavelength (μm)	Laser Type	Wavelength (μm)	Pulse Duration (s)	Class 1 (J)	Class 3b (J)	Class 4 (J)
Ultraviolet						
0.180 to 0.400	Excimer (ArF)	0.193	20×10^{-9}	$\leq 1.9 \times 10^{-6}$ *	> Class 1 but ≤ 0.125	> 0.125
	Excimer (KrF)	0.248	20×10^{-9}	$\leq 1.9 \times 10^{-6}$ *	> Class 1 but ≤ 0.125	> 0.125
	Neodymium:YAG Quadrupled (Q-sw)	0.266	20×10^{-9}	$\leq 1.9 \times 10^{-6}$ *	> Class 1 but ≤ 0.125	> 0.125
	Excimer (XeCl)	0.308	20×10^{-9}	$\leq 4.3 \times 10^{-6}$ *	> Class 1 but ≤ 0.125	> 0.125
	Nitrogen	0.337	20×10^{-9}	$\leq 3.6 \times 10^{-6}$ *	> Class 1 but ≤ 0.125	> 0.125
	Excimer (XeF)	0.351	20×10^{-9}	$\leq 4.3 \times 10^{-6}$ *	> Clas 1 but ≤ 0.125	> 0.125
Visible						
0.400 to 0.700	Rhodamine 6G (Dye Laser)	0.450-0.650	1×10^{-6}	$\leq 0.2 \times 10^{-4}$	> Class 1 but ≤ 0.03	> 0.03
	Copper Vapor	0.510, 0.578	25×10^{-9}	$\leq 2 \times 10^{-7}$	> Class 1 but ≤ 0.03	> 0.03
	Neodymium:YAG Doubled (Q-sw)	0.532	20×10^{-9}	$\leq 2 \times 10^{-7}$	> Class 1 but ≤ 0.03	> 0.03
	Ruby (Q-sw)	0.6943	20×10^{-9}	$\leq 2 \times 10^{-7}$	> Class 1 but ≤ 0.03	> 0.03
	Ruby (Long Pulse)	0.6943	1×10^{-3}	$\leq 4 \times 10^{-6}$	> Class 1 but ≤0.03	> 0.03
Near Infrared						
0.700 to 1.4	Ti:Sapphire	0.700-1.000	6×10^{-6}	$\leq 1.9 \times 10^{-7}$	> Class 1 but ≤ 0.03 C_A	> 0.03 C_A
	Alexandrite	0.720-0.800	1×10^{-6}	$\leq 0.76 \times 10^{-4}$	> Class 1 but ≤ 0.03 C_A	> 0.03 C_A
	Neodymium:YAG (Q-sw)	1.064	20×10^{-9}	$\leq 2 \times 10^{-6}$	> Class 1 but ≤ 0.15	> 0.15
Far Infrared						
1.4 to 10^3	Erbium:Glass (Q-sw)	1.540	10×10^{-9}	$\leq 7.9 \times 10^{-3}$	> Class 1 but ≤ 0.125	> 0.125
	Co:Magnesium-Fluoride	1.8-2.5	80×10^{-6}	$\leq 7.9 \times 10^{-4}$	> Class 1 but ≤ 0.125	> 0.125
	Holmium	2.100	250×10^{-6}	$\leq 7.9 \times 10^{-4}$	> Class 1 but ≤ 0.125	> 0.125
	Hydrogen Fluoride	2.600-3.000	0.4×10^{-6}	$\leq 1.1 \times 10^{-4}$	> Class 1 but ≤ 0.125	> 0.125
	Erbium	2.940	250×10^{-6}	$\leq 5.6 \times 10^{-4}$	> Class 1 but ≤ 0.125	> 0.125
	Carbon Dioxide (Q-sw)	10.6	100×10^{-9}	$\leq 7.9 \times 10^{-5}$	> Class 1 but ≤ 0.125	> 0.125
	Carbon Dioxide	10.6	1×10^{-3}	$\leq 7.9 \times 10^{-4}$	> Class 1 but ≤ 0.125	> 0.125

* Assuming that both eye and skin maybe exposed, i.e., 1.0 mm beam (area of limiting aperture = 7.9×10^{-3} cm^2).

From ANSI Z136.1 (1993) Safe Use of Lasers, for complete information on laser safety, refer to the ANSI Z136 series of laser safety standards, contact Laser Institute of America at 1-800-34LASER for additional information.

TABLE 6C
Intrabeam MPE for the Eye for Selected CW Lasers

Laser Type	Wavelength	Maximum Permissible Exposure		Exposure Duration
	(μm)	($J \cdot cm^{-2}$)	($W \cdot cm^{-2}$)	(s)
Argon	0.275	3×10^{-3}	—	10 to 3×10^4
Helium-Cadmium	0.325	1	—	10 to 3×10^4
Argon	0.351	1	—	10 to 3×10^4
Helium-Cadmium	0.4416	—	2.5×10^{-3}	0.25
Argon	0.488, 0.514	10×10^{-3}	—	10 to 10^4
Argon	0.488, 0.514	—	10^{-6}	$> 10^4$
Helium-Neon	0.632	—	2.5×10^{-3}	0.25
Helium-Neon	0.632	10×10^{-3}	1.0×10^{-3}	10
Helium-Neon	0.632	0.17	—	$> 453\ ^*$ to 10^4
Helium-Neon	0.632	—	17×10^{-6}	$> 10^4$
Krypton	0.647	—	2.5×10^{-3}	0.25
Krypton	0.647	10×10^{-3}	1.0×10^{-3}	10
Krypton	0.647	0.280	—	$> 871\ ^*$ to 10^4
Krypton	0.647	—	28×10^{-6}	$> 10^4$
InGaAlP	0.670	—	2.5×10^{-3}	0.25
GaAs	0.905	—	0.8×10^{-3}	> 1000
Neodymium: YAG	1.064	—	1.6×10^{-3}	> 1000
InGaAsP	1.310	—	12.8×10^{-3}	> 1000
InGaAsP	1.550	—	0.1	> 10
Carbon-Dioxide	10.600	—	0.1	> 10

* T_1: see Table 6 and Figure 9.

From ANSI Z136.1 (1993) Safe Use of Lasers, for complete information on laser safety, refer to the ANSI Z136 series of laser safety standards, contact Laser Institute of America at 1-800-34LASER for additional information.

TABLE 6D
Intrabeam MPE for the Skin for Selected CW Lasers

Laser Type	Wavelength	Maximum Permissible Exposure		Exposure Duration
	(μm)	($J \cdot cm^{-2}$)	($W \cdot cm^{-2}$)	(s)
Argon	0.275	3×10^{-3}	—	3×10^4
Helium-Cadmium	0.325	1	—	10 to 1000
Argon	0.351	1	—	10 to 1000
Helium-Cadmium	0.4416	—	0.2	> 10
Argon	0.488	—	0.2	> 10
Argon	0.514	—	0.2	> 10
Helium-Neon	0.6328	—	0.2	> 10
Krypton	0.647	—	0.2	> 10
GaAs	0.905	—	0.5	> 10
Neodymium: YAG	1.064	—	1.0	> 10
Carbon-Dioxide	10.600	—	0.1	> 10

From ANSI Z136.1 (1993) Safe Use of Lasers, for complete information on laser safety, refer to the ANSI Z136 series of laser safety standards, contact Laser Institute of America at 1-800-34LASER for additional information.

TABLE 6E
Intrabeam MPE for the Eye and Skin for Selected Pulse Lasers

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

From ANSI Z136.1 (1993) Safe Use of Lasers, for complete information on laser safety, refer to the ANSI Z136 series of laser safety standards, contact Laser Institute of America at 1-800-34LASER for additional information.

TABLE 7
Optical Densities Required for Intrabeam Viewing at Selected Laser Wavelengths

Laser Type	Wavelength (μm)	Power	Optical Density: Exposure Time: (s) 0.25	10	600	3×10^4
XeCl	0.308[b]	50 Watts	-.-	6.2	8.0	9.7
XeFl	0.351[b]	50 Watts	-.-	4.8	6.6	8.3
Argon	0.514	1.0 Watt	3.0	3.4	5.2	6.4
Argon	0.514	5.0 Watts	3.7	4.1	5.9	7.1
Krypton	0.530	1.0 Watt	3.0	3.4	5.2	6.4
Krypton	0.568	1.0 Watt	3.0	3.4	4.9	6.1
HeNe	0.633	0.005 Watt	0.7	1.1	1.7	2.9
Krypton	0.647	1 Watt	3.0	3.4	3.9	5.0
GaAs	0.840[b]	50mW	-.-	1.8	2.3	3.7
Nd:YAG	1.064[b]	100Watt (CW)	-.-	4.7	5.2	5.2
Nd:YAG	1.064[b]	(Q-switched)[a]	-.-	4.5	5.0	5.4

a Repetitively pulsed at 11 Hz., 12ns pulses, 20mJ/pulse.
b OD for UV & FIR beams computed using 1mm limiting aperture which presents a "worst case" scenario. All visible/NIR computations assume 7mm limiting aperture.
-.- Invisible beams; aversion response time does not apply.

NOTE: OD values obtained using ANSI Z-136.1 (1986) MPE critieria.

Taken from *Laser Safety Officer Course*, Rockwell Industries, 1994.