Northern Illinois University
Laser Safety Manual

Laser Safety
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1.0 Introduction

Lasers have become a prominent tool in many research areas at Northern Illinois University. If improperly used or controlled, class 3b and 4 lasers (see Section 4.0: Laser classification) can produce injuries (such as burns, blindness, or electrocution) to operators and other personnel, including uninitiated visitors to laboratories, and cause significant damage to property.

Individual users of these high-powered lasers must be adequately trained to ensure full understanding of the safety practices outlined in Northern' s Laser Safety program and the State regulations. The requirements in this manual only apply to class 3b and 4 lasers.

Laser safety policies and procedures follow the requirements of Illinois Administrative Code Title 32 Part 315 "Standards for Protection Against Laser Radiation." Besides many prescriptive requirements, the regulation adopts by reference certain sections of ANSI Z136.1, "American National Standard for Safe Use of Lasers." A copy of the standard is available for review at the Office of Research Compliance and Integrity (ORCIS) located in 105 Lowden Hall.

Each investigator who uses a class 3b or 4 laser system is encouraged to obtain a copy of the ANSI standard to keep in the laboratory. The standard contains useful charts, tables and sample calculations to help with hazard evaluations in the lab. One source for the standard is Laser Institute of America (www.laserinstitute.org).

2.0 Program Organization and Responsibilities

The University has established a Laser Safety Committee responsible for formulating policy related to the safe use of lasers. The Committee is also charged with monitoring the University's compliance with regard to federal and state regulations for the safe use of laser radiation. The Laser Safety Officer (LSO) is responsible for ensuring that the policies and guidelines established by the Committee are implemented. The LSO is also responsible for informing the Committee of any compliance issues at the University.

As the overall manager of the laser safety program, the LSO is responsible for monitoring laser safety practices and informing responsible persons of situations where recommended safety practices are not being followed. The LSO provides basic laser safety awareness training and maintains training resources, records and some supplies (signs, labels, etc.) to assist laser users. The LSO also maintains copies of current standards and regulations, which may be reviewed by users.

It is the policy of Northern Illinois University that the principal investigator (PI), or faculty member in charge of a laboratory, is responsible for safety associated with laser use in their area. For class 3b and 4 lasers, this responsibility includes, but is not limited to:

- developing written operating, safety and emergency procedures,
- performing a hazard evaluation in each laboratory (see Appendix B),
- training operators in operating, safety and emergency procedures (see Section 5.0),

- procuring protective eyewear appropriate for the wavelength of the laser radiation and requiring its use (see Section 6.0),
- proper posting of signs and warnings,
- registering each new laser system with ORCIS, and
- notifying ORCIS when a laser system is permanently taken out of service.

Individual users of lasers shall follow the standard operating procedure for that laser. Individual users also must inform the PI of any departure from the established procedure including any exposure incident involving an injury from direct or reflected laser radiation.

3.0 Laser Registration

All class 3b and class 4 lasers must be registered with ORCIS. Contact the Laser Safety Officer to register your laser. The following information is needed for registration: laser classification, make, model, serial number, output power, wavelength and location.

Lasers are to be registered before being placed in service so the LSO can verify that the system is operating within University and State requirements for safe use. On behalf of the University, ORCIS must register each operating system with the Illinois Emergency Management Agency (IEMA) each calendar year. Therefore, when a laser system is taken out of service, ORCIS must be notified as well.

4.0 Laser Classification

Lasers are divided into several classes depending upon the power or energy of the beam and the wavelength of the emitted radiation. Laser classification is based on the laser's potential for causing immediate injury to the eye or skin and/or potential for causing fires from direct exposure to the beam or from reflections from reflective surfaces.

Commercially produced lasers are classified and identified by labels affixed to the laser. In cases where the laser has been fabricated on campus or is otherwise not labeled, the LSO should be consulted on the appropriate laser classification and labeling. Lasers are classified using the physical parameters of power, wavelength, and exposure duration. A description of laser classes follows.

Class 1 lasers

Class 1 lasers are considered to be incapable of producing damaging radiation levels, and are therefore exempt from most control measures or other forms of surveillance.

Class 2 lasers

Class 2 lasers emit radiation in the visible portion of the spectrum, and protection is normally afforded by the normal human aversion response (blink reflex) to bright radiant sources. They may be hazardous if viewed directly for extended periods of time.

Class 3 lasers

Class 3a lasers are those that normally would not produce injury if viewed only momentarily with the unaided eye. They may present a hazard if viewed using collecting optics, e.g., telescope, microscope, or binoculars. Example: visible light lasers above 1 milliwatt but not exceeding 5 milliwatts radiant power.

Class 3b lasers can cause severe eye injuries from direct viewing of the beam or specular reflections. A Class 3 laser is not normally a fire hazard. Example: visible light continuous wave lasers above 5 milliwatts but not exceeding 500 milliwatts radiant power.

Class 4 lasers

Class 4 lasers are a hazard to the eye from the direct beam and specular reflections and sometimes even from diffuse reflections. Some Class 4 lasers can also start fires and damage skin.

An investigator is only required to register Class 3b and 4 lasers with ORCIS. Laser systems containing embedded Class 3b or 4 lasers are exempt when the systems' lower classification is appropriate due to engineering features limiting accessible emission.

5.0 Operator Training and Qualification

Only trained and qualified employees may operate Class 3b and Class 4 lasers. To be qualified, a laser operator must meet both the training requirements outlined below and operational qualifications established by the Principle Investigator (PI). The PI is responsible for ensuring that all persons who work in areas where Class 3b or 4 lasers are used are provided with training that is sufficient to allow understanding of the risks from laser radiation. Workers who operate lasers must also receive written safety instructions (standard operating procedures, see Appendix A), so that they can properly utilize equipment and follow all safety procedures.

The PI or laboratory supervisor must retain records of operator training. Each of these individuals must also be registered as a laser operator with the LSO. To be registered as a laser operator, the individual must complete a basic awareness training course on general laser safety awareness, and complete annual refresher training thereafter available through ORCIS.

The basic awareness training for new operators is only one part of the training requirement. In addition, operators must be provided with lab-specific safety training regarding the procedures and equipment used in that laser laboratory. The lab-specific training, by nature, is part of the standard operating procedure for a particular lab. All training must be documented.

Safety training is to be provided before persons are permitted to operate lasers without supervision. The individual providing the lab-specific training must be designated by the PI and have knowledge adequate and appropriate to the subject matter being presented. This would include, but not be limited to: knowledge in lasers, laser safety concepts, laser safety standards, and each laser system used in the lab.

On-the-job training for Class 3b and Class 4 laser operators must include a thorough review of hazards associated with each laser that a person may operate. The training must also include the protective methods employed by the laboratory. At a minimum, the training must include basic instruction on the following topics:

- the biological effects of laser radiation (see Appendix B),
- the physical properties of lasers, including specular and diffuse reflection,
- access control,
- use of protective eyewear,
- control of related non-beam hazards, including electrical safety, fire safety, and chemical safety related to handling and storage (see Appendix B), and
- emergency response procedures.

6.0 Eye Protection

Each PI must ensure that appropriate eye protection is provided to individuals working with lasers and must ensure that protection is worn. Laser protective eyewear is specific to the types of laser radiation in the lab. Windows where Class 3b or 4 beams could be transmitted causing hazards in uncontrolled areas are to be covered or otherwise protected during laser operation. The following guidelines are suggested for maximum eye protection.

- Whenever possible, confine (enclose) the beam (e.g., use beam pipes) and provide non-reflective beam stops to minimize the risk of accidental exposure or fire.
- Use fluorescent screens or similar "targets" to align the beam.
- Avoid direct intrabeam exposure to the eyes. Direct viewing must NOT be used to align laser optical systems.
- Use the lowest laser power possible for beam alignment procedures.
- Whenever possible, use Class 2 lasers for preliminary alignment procedures.
- Keep optical benches free of unnecessary reflective items.
- Confine the beam to the optical bench unless necessary for an experiment.
- Whenever possible, keep the beam in a single plane on the bench.
- Use barriers at the sides of benches or other enclosures.
- Do not use room walls to align Class 3b or 4 laser beams.
- Use non-reflective tools. Remember that some tools that seem to be non-reflective for visible light may be very reflective for the non-visible spectrum.
- Do not wear reflective jewelry when working with lasers. Metallic jewelry also increases shock hazards.

Protective glasses must be worn whenever working with Class 3b or 4 lasers with open beams or when reflections can occur. In general, laser glasses may be selected on the basis of protection against reflections, especially diffuse reflections. Protective eyewear is designed to provide protection to a level where the natural aversion reflex will prevent eye injuries. Eye protection may also be selected to protect against stray reflections.

Selecting protective glasses or goggles that allow some visibility of the beam may make it more likely that individuals will wear the eye protection. Also, the increased visibility afforded at this level of protection decreases the potential for other accidents in the lab, such as tripping. Glasses designed for limited protection, such as those currently under discussion, are not appropriate for intrabeam viewing or for highly specular reflections. Additionally, side shields should be a part of any protective eyewear.

Factors to consider in selection of laser protective eyewear include the following:

- wavelength or spectral region of laser radiation,
- optical density at the particular wavelength(s),
- maximum irradiance (W/cm2) or beam power (W), for which the eyewear provides protection for at least 5 seconds,
- type of laser system,
- power mode, single pulse, multiple pulse or CW, and the strength, i.e., both peak and average power,
- possibilities of reflections, specular and diffuse,
- field of view provided by the design,
- availability of prescription lenses or sufficient size of goggle frames to permit wearing of prescription glasses inside of goggles,
- comfort,
- ventilation ports to prevent fogging,
- effect upon color vision,
- absence of irreversible bleaching if filter is exposed to high peak irradiances,
- impact resistance, and
- the ability to perform required tasks while wearing eyewear.

For double wavelength systems, glasses (goggles) can be obtained with flip-down lenses to protect against the two wavelengths. Where a laser produces invisible beams and visible beams, the inner lens can be designed to protect against the invisible radiation and the flip-down lens to protect against the visible laser radiation.

7.0 Operational Requirements

The PI must provide written operating and safety procedures to personnel who operate lasers. These procedures are to include all restrictions required for the safe operation of each laser. They may incorporate sections of the manufacturer’s technical manuals if those documents are available to the operator. Personnel shall be instructed in and be able to demonstrate competence with the PI's operating and safety procedures before operating lasers. See Sample Laser SOP for sample procedures and templates.

In each laser use location, a hazard evaluation must be performed when a new system is commissioned to determine where an individual may exceed the maximum permissible exposure (MPE). This hazard evaluation, along with the guidance in ANSI Z136.1, will determine where and what warning signs are to be posted. For systems already in use without a hazard evaluation having been performed, the evaluation shall be completed as soon as practicable. The PI is responsible for contacting the LSO for the hazard evaluation and proper posting of caution signs. Signs will be provided by ORCIS at no cost to the PI. Guidance on hazard evaluations can be found in Appendix A of this Handbook.

For laser systems with unenclosed beam paths, the hazard evaluation must include the potential hazards that may be encountered from reflective surfaces. Reflective surfaces shall be excluded from the beam path at all points where the laser radiation exceeds the MPE. No individual may be exposed to levels of laser radiation higher than the MPE, as described in Tables A and B. Measurements and calculations performed to determine MPE limits shall be made in a manner consistent with the criteria contained in ANSI Z136.1, a copy of which is available for review at ORCIS.

No laser may be operated or made ready for operation until the area along all points of the beam path where the laser radiation will exceed the MPE is clear of individuals, unless the individuals are wearing appropriate protective devices. In crowded laboratories this may require the use of curtains designed to block laser radiation. Alignment of laser optical systems shall be performed in a manner that assures that no one is exposed to laser radiation above the MPE. A controlled area must be established when exposure to laser radiation in excess of the MPE limit is possible. Access to the controlled area shall be only by permission of an experienced, trained operator.

The laser system shall be operated at all times under the direct supervision or control of an experienced, trained operator who maintains visual surveillance of conditions for safe use and can terminate laser emission in the event of any unsafe condition of use. Unattended use of the laser system can be permitted only when the PI has implemented control measures that provide adequate protection and has provided laser safety training to those who may enter the laser controlled area during times of unattended use. Engineered control measures are always preferred over procedural controls.

8.0 Warning Signs and Labels

A controlled area, in which access is restricted for the purpose of protection from laser radiation, must be conspicuously posted with caution signs as prescribed for the class of the laser. Because the warning sign must have certain prescribed wording at specific locations depending on the class and type of laser, these signs are provided to the laboratory by ORCIS. Additionally, the aperture through which the laser radiation is emitted must be labeled with a prescribed warning that laser radiation is emitted from the aperture.

For enclosures that are designed to be removed during normal operations, maintenance or servicing and that would permit human access to the beam an additional warning sign must include a prescribed warning that there is laser radiation when opened. The specific requirements for the warning signs and labels may be found in ANSI Z136.1 or in 32 Ill. Adm. Code 315.150, and will be provided by ORCIS.

9.0 Notifications and Reports

Each laser investigator must notify the LSO immediately by telephone of any incident involving exposure to laser radiation that has caused injury to an individual in the course of use, handling, operation, manufacture or discharge of a laser system. After the initial notification, the PI must submit a report of the incident through the ORCIS website using the Reporting Incidents button and submit it three days after the incident. The LSO will render assistance with this process as necessary.

- The full name of each exposed individual
- An estimate of each individual’s exposure (in multiples of MPE), if possible
- The levels of laser radiation involved in radiant energy (J/cm2) or radiant power (W/cm2)
- The cause of the exposure
- A description of any injuries

Date	Reviewed by	Changes
2/22/2023	M. Crase	Minor changes

Appendix A Hazard Evaluation

The primary basis for any hazard evaluation is the Maximum Permissible Exposure (MPE) limit for the laser system being evaluated. One important factor for determining the MPE is the accidental exposure time, since all exposures are assumed to be accidental. The following table shows the exposure duration assumed for an accidental exposure from Continuous Wave lasers in three broad parts of the electromagnetic spectrum.

Part of Spectrum	Wavelength Range (nm)	Exposure Duration
Ultra Violet	180-400	Beam-on time, up to 8 hrs
Visible InfraRed	400-700 700-106	0.25 sec 10 sec

Using those assumed exposure durations and the data from Tables A or B, the MPE can be determined. The units of MPE are either energy or power per unit surface area.

For pulsed lasers, the method is somewhat more complex. Besides the wavelength, you must know the pulse duration at full width at half-power (FWHM). Repetitively pulsed lasers are subject to three rules:

Any single pulse in the train must not exceed the MPE
The exposure from any group of pulses delivered in time T must not exceed the MPE for time T.
For thermal injury, the exposure for any single pulse within a group of pulses must not exceed the single-pulse MPE multiplied by a multiple-pulse correction factor CP (see table 3).

Once the MPE has been determined for a particular laser system, a Nominal Hazard Zone (NHZ) must be established. The NHZ is the space within which the level of direct, reflected or scattered laser light exceeds the MPE for that laser. Due to divergence, as the distance from the source or focus of the beam (or its reflection) increases, the irradiance (E in W/cm2) decreases. That boundary defines the NHZ.

A complete hazard evaluation involves more than just the MPE and NHZ, however. Many laser systems also present non-beam hazards that must be considered. These hazards can be grouped into four general groupings: chemical, biological, physical and other. Chemical hazards include those associated with dyes and solvents, compressed gases and laser-generated air contaminants. Hazardous biological agents include cells and microorganisms and some laser-generated air contaminants. Physical hazards are plasma radiation, collateral radiation (such as x-rays), electricity and noise. Other hazards that may warrant serious consideration are fires, explosions, ergonomics and robotics (more likely in an industrial setting).

Sample MPE Calculations

Case 1: Eye exposure to a CW Nd:YAG laser

Wavelength (λ) = 1.064 µm = 1,064 nm
Assume accidental eye exposure (probably from specular or diffuse reflection). Exposure duration t = 10s (since not in 400 to 700 nm visible range)
From Table A,
MPE = 5.0 Cc x 10-3 W/cm2.
Using CC = 1 from Table C for λ = 1.064 µm, MPE = 5.0 x 10-3 W/cm2 or 0.005 W/cm2.

Case 2: Skin exposure to a CW Nd:YAG laser

Assume exposure duration is 10 s or longer. Using Table B for skin exposure,
MPE = 0.2 CA W/cm2.
From Table C, CA = 5.0 for λ = 1.064 µm. MPE = 1.0 W/cm2.

Case 3: Eye exposure to single-pulsed Ruby laser

λ = 694 nm
Pulse duration 30 ns, FWHM

Using Table A for pulses between 10-9 and 18 x 10-6 seconds, MPE = 0.5 x 10-6 J/cm2

Case 4: Eye exposure to Repetitively-Pulsed Nd:YAG laser

Pulse Repetition Frequency (PRF) = 30 hz (pulses per second) Variable pulse width, from 7 to 30 ms

Rule 1 – No single pulse in a chain may exceed the MPE For worst case, use smallest pulse width (7 ms)
For λ = 1.064 µm, MPE_{SP} = 9.0 CC t 0.75 x 10-3
From table C, CC = 1.0, so
$MPE_{SP} = (9.0)(1.0)(7x10^{-3})^{0.75} \times 10^{-3}$ J/cm2 $MPE_1 = 0.218$ mJ/cm^2.

Rule 2 – Average Power MPE
The exposure from any group of pulses delivered in time T must not exceed the MPE for time T.
For infrared region T = 10 seconds.
Divide MPE for a 10-second exposure by the number of pulses, n, during the 10-second period.
For this example, n = 300, so
MPE/pulse = $((9.0)(1.0)(10^{0.75})$ mJ/cm^2)/300)
$MPE_2 = 0.169$ mJ/cm^2.

Rule 3 – Multiple-Pulse MPE

For thermal injury, the exposure for any single pulse within a group of pulses must not exceed the single-pulse MPE multiplied by a multiple-pulse correction factor C_P.

From Table 3, $C_P = n^{-0.25}$, where n is the number of pulses in T_{max} = 10 seconds.

$C_P = 300^{-0.25} = 0.240$

MPE_3 = 52.3 μJ/cm^2.

Conclusion: Rule 3 produces the most limiting case, so

MPE/pulse = 52.3 μJ/cm^2

To express the limit as average irradiance MPE, multiply by the PRF = 30 Hz

MPE_E = 1.57 mW/cm2 or 1.57×10^{-3} W/cm^2.

Sample NHZ Calculation

Case: CW CO2 laser, intrabeam case

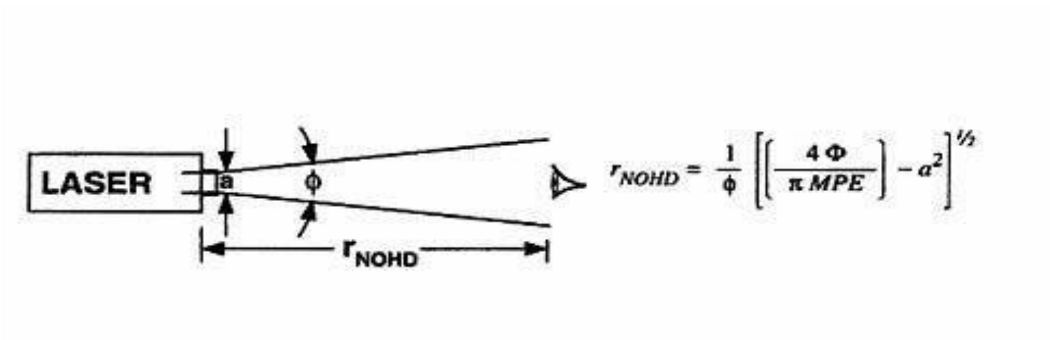
Average power Φ = 2000 W

Beam divergence φ = 4 mrad = .004 radians

Emergent Beam diameter (a) = 1.0 cm

λ = 10.6 μm

MPE = 0.1 W/cm^2



rNOHD = 1/.004 ((4(2000)/π(0.100) – 1.0^2)$^{1/2}$

rNOHD = 250(25,465)

rNOHD = 250(160) = 39,900 cm = 399 m = 1310 ft = 0.248 mi.

As you can see, this case would require some barriers in place to stop the beam from affecting a large region. For other examples of laser range equations used for Nominal Hazard Distances, see pages 125 and 126 of ANSI Z136.1-2000.

Appendix B Biological Effects of Laser Radiation

Biological effects of laser radiation are generally caused by thermal effects to the skin or by photo-chemical effects to portions of the eye. Because of the high radiant power of many laser systems, a very short exposure can cause a lasting effect. Most accidental injuries are caused by unexpected reflections and the damage usually occurs before anyone knows it is happening.

Although class 4 lasers by definition can cause damage to the skin through thermal effects, the primary hazard from laser radiation is to the eye. The type, location and severity of the ocular damage vary with the energy, power and angle of incidence of the beam on the eye tissue. The most significant variation is by wavelength. Ultraviolet radiation (180-400 nm) generally affects the lens and cornea through photochemical reactions while the most severe effects are to the retina from the visible (400-700 nm) and near-infrared (700-1400 nm) regions. Effects from long wavelengths in the infrared region of the spectrum are primarily in the cornea which replaces cells rapidly. These effects are generally considered to be temporary.

The severity of the retinal damage depends on where the incident beam strikes the tissue at the rear of the eye. Cones are used for color and detail and if these are damaged, they recover slowly if at all. Rods are used for low-light vision and recover better from severe damage.
Lesions in the retina are often permanent, causing a spot to appear in every image. Large amounts of energy deposited by ultra violet radiation to the lens can cause opacity and cataracts.

Table A MPE for Ocular Exposure (Intrabeam Viewing)

Wavelength (□m)	Exposure Duration, t (s)	MPE	
		(J cm-2)	(W cm-2)
Ultraviolet			
0.180 to 0.302	10-9 to 3 x 104	3 x 10-3	
0.303	10-9 to 3 x 104	4 x 10-3	
0.304	10-9 to 3 x 104	6 x 10-3	
0.305	10-9 to 3 x 104	10 x 10-3	
0.306	10-9 to 3 x 104	16 x 10-3	
0.307	10-9 to 3 x 104	25 x 10-3	
0.308	10-9 to 3 x 104	40 x 10-3	
0.309	10-9 to 3 x 104	63 x 10-3	
0.310	10-9 to 3 x 104	0.1	
0.311	10-9 to 3 x 104	0.16	
0.312	10-9 to 3 x 104	0.25	
0.313	10-9 to 3 x 104	0.40	
0.314	10-9 to 3 x 104	0.63	
0.315 to 0.400	10-9 to 10	0.56 t0.25	
0.315 to 0.400	10 x 3 x 104	1.0	
NOTE: To calculate MPE, use the J/cm2 value shown or 0.56 t0.25, whichever is lower.			
Visible and Near Infrared			
0.400 to 0.700	10-9 to 18 x 10-6	0.5 x 10-6	
0.400 to 0.700	18 x 10-6 to 10	1.8 t0.75x 10-3	
0.400 to 0.450	10 to 100	1.0 x 10-2	
0.450 to 0.500	10 to T1		1 x 10-3
0.450 to 0.500	T1 to 102	CB x 10-2	
0.400 to 0.500	100 to 3 x 104		CB x 10-4
0.500 to 0.700	10 to 3 x 104		1 x 10-3
0.700 to 1.050	10-9 to 18 x 10-6	5.0 CA x 10-7	
0.700 to 1.050	18 x 10-6 to 10	1.8 CA t0.75 x 10-3	
0.700 to 1.050	10 to 3 x 104		CA x 10-3
1.050 to 1.400	10-9 to 50 x 10-6	5.0 CC x 10-6	
1.050 to 1.400	50 x 10-6 to 10	9.0 CC t0.75 x 10-3	
1.050 to 1.400	10 to 3 x 104		5.0 CC x 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 t0.25	

1.400 to 1.500	10 to 3 x 104		0.1
1.500 to 1.800	10-9 to 10	1.0	
1.500 to 1.800	10 to 3 x 104		0.1
1.800 to 2.600	10-9 to 10-3	0.1	
1.800 to 2.600	10-3 to 10	0.56 t0.25	
1.800 to 2.600	10 to 3 x 104		0.1
2.600 to 103	10-9 to 10-7	1.0 x 10-2	
2.600 to 103	10-7 to 10	0.56 t0.25	
2.600 to 103	10 to 3 x 104		0.1
Notes: For multiple pulses, apply correction factor CP given in Table C.			
General Notes: The MPE for diffuse reflections at wavelengths between 0.400 and 1.400 □m is obtained by multiplying the corresponding MPEs above by CE (see Table C for correction factors and T1). For repeated (pulsed) exposures see ANSI Z136.1-2000, section 8.2.3.			

Source: ANSI Z136.1-2000

Table B MPE for Skin Exposure

Wavelength (□m)	Exposure Duration, t (s)	MPE (J cm-2)	MPE (W cm-2)
Ultraviolet			
0.180 to 0.302	10-9 to 3 x 104	3 x 10-3	
0.303	10-9 to 3 x 104	4 x 10-3	
0.304	10-9 to 3 x 104	6 x 10-3	
0.305	10-9 to 3 x 104	1.0 x 10-2	
0.306	10-9 to 3 x 104	1.6 x 10-2	
0.307	10-9 to 3 x 104	2.5 x 10-2	
0.308	10-9 to 3 x 104	4.0 x 10-2	
0.309	10-9 to 3 x 104	6.3 x 10-2	
0.310	10-9 to 3 x 104	1.0 x 10-1	
0.311	10-9 to 3 x 104	1.6 x 10-1	
0.312	10-9 to 3 x 104	2.5 x 10-1	
0.313	10-9 to 3 x 104	4.0 x 10-1	
0.314	10-9 to 3 x 104	6.3 x 10-1	
0.315 to 0.400	10-9 to 10	0.56 t0.25	
0.315 to 0.400	10 x 103	1	
0.315 to 0.400	103 to 3 x 104		1 x 10-3
NOTE: 1. To calculate MPE, use the J/cm2 value shown or 0.56 t0.25, whichever is lower.			
Visible and Near Infrared			
Wavelength (□m)	Exposure Duration, t (s)	MPE (J cm-2)	MPE (W cm-2)
0.400 to 1.400	10-9 to 10-7	2CA x 10-2	
	10-7 to 10	1.1CA t0.25	
	10 to 3 x 104		0.2CA
Far Infrared			
Wavelength (□m)	Exposure Duration, t (s)	MPE (J cm-2)	MPE (W cm-2)
1.400 to 1.500	10-9 to 10-3	10-1	
1.400 to 1.500	10-3 to 10	0.56 t0.25	
1.400 to 1.500	10 to 3 x 104		0.1
1.500 to 1.800	10-9 to 10	1.0	
1.500 to 1.800	10 to 3 x 104		0.1
1.800 to 2.600	10-9 to 10-3	0.1	
1.800 to 2.600	10-3 to 10	0.56 t0.25	
1.800 to 2.600	10 to 3 x 104		0.1
2.600 to 103	10-9 to 10-7	1 x 10-2	
2.600 to 103	10-7 to 10	0.56 t0.25	
2.600 to 103	10 to 3 x 104		0.1

Source: ANSI Z136.1-2000

Parameters/Correction Factors	Wavelength (□m)
T = 10 x 1020(□-0.450) *	0.450 to 0.500
T = 10 x 10(□-1.5)/98.5 **	0.400 to 1.400
CB = 1.0	0.400 to 0.450
C = 1020(□-0.450)	0.450 to 0.600
CA = 1.0	0.400 to 0.700
C = 102(□-0.700)	0.700 to 1.050
CA = 5.0	1.050 to 1.400
C = n-0.25 ***	0.180 to 1000
CE = 1.0 □<□min	0.400 to 1.400
CE = □/□min □min□□□□max	0.400 to 1.400
CE = □2/(□max□min) □>□max	0.400 to 1.400
CC = 1.0	1.050 to 1.150
C = 1018(□-1.150)	1.150 to 1.200
CC = 8	1.200 to 1.400

* T1 = 10 s for □□= 0.450 □m, and T1 = 100 s for □□= 0.500 □m.
** T2 = 10 s for □□< 1.5 mrad, and T2 = 100 s for □□> 100 mrad.
*** See ANSI Z136.1-2000 Section 8.2.3 for discussion of CP and Section 8.2.3.2 for discussion of pulse repetition frequencies below 55 kHz (0.4 to 1.05 □m) and below 20 kHz (1.05 to 1.4 □m)

Notes:
For wavelengths between 0.400 and 1.400 □m: □min = 1.5 mrad and □max = 100 mrad
Wavelengths must be expressed in micrometers and angles in milliradians for calculations. The wavelength region □1 to □2
means □1 □□□□□□□2, e.g., 0.550 to 0.700 □m means 0.550 < □□< 0.700 □m.

Source: ANSI Z136.1-2000