ANSI Z136.1 - 2022

American National Standard

American National Standard for Safe Use of Lasers

ANSI®
Z136.1 – 2022
Revision of
ANSI Z136.1-2014

American National Standard for Safe Use of Lasers

Secretariat
Laser Institute of America

Approved August 3, 2022
American National Standards Institute, Inc.

American National Standard

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Published by

Laser Institute of America
12001 Research Parkway, Suite 210
Orlando, FL 32826

ISBN: 978-1-940168-29-6 (Paperback)

Printed in the United States of America.

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American National Standard for Safe Use of Lasers

1. General

1.1 Scope.

This standard provides recommendations for the safe use of lasers and laser systems that operate at wavelengths between 180 nm and 1000 µm.

1.2 Application.

The objective of this standard is to provide reasonable and adequate guidance for the safe use of lasers and laser systems. A practical means for accomplishing this is to

a) classify lasers and laser systems according to their relative hazards, and

b) specify appropriate controls for each classification.

The basis of the hazard classification scheme in Section 3 of this standard is the ability of the laser beam to cause biological damage to the eye or skin during operation. Control requirements depend primarily on the class of the laser and are described in Sections 4 and 5.

The recommended procedure for using this standard is as follows:

a) Determine the appropriate class of the laser or laser system.

b) Comply with the requirements specified for that class of laser or laser system. Requirements may be recommendations (should) or requirements (shall).

c) Perform a hazard evaluation appropriate to the application, environment, and personnel, and determine if any requirements should be added or removed.

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

1.2.1 Horizontal and Vertical Standards. Standards can be characterized as either horizontal or vertical. Ideally, a horizontal standard would contain primarily general principles, concepts, definitions, terminology, and similar general information applicable over the subject area of the standard. Vertical standards would then contain only information specific to particular applications or products in that subject area. While vertical standards are based on the horizontal standard, they expand upon the information in that standard for specific application areas. Each vertical standard should not include information extraneous to its intended application.

In the Z136 series, this Z136.1 standard serves as a horizontal standard and supplies the following information for all other standards in the series:

a) hazard classification scheme,

b) exposure limits, exposure limit definitions and tables,

alignment eyewear. Protective eyewear for visible wavelengths with an appropriate optical density (OD) to allow the user to see the termination point of the beam during alignment procedures.

alpha max (α_{max}). The angular subtense of an extended source beyond which additional subtense does not contribute to the hazard and need not be considered. (see Figure 14 and Figure B4 in Appendix B for illustrations). *Unit:* radians (rad).

NOTE—This value varies with the exposure duration for retinal thermal effects (see Table 8b).

alpha min (α_{min}). The angular subtense of a source below which the source can be effectively considered as a point source. Alpha min has a value of 1.5 mrad. *Unit:* radians (rad).

aperture. An opening, window, or lens through which optical radiation can pass. The aperture limits the energy or power for measurement or exposure.

apparent visual angle (α). The angular subtense of the source as calculated from source size and distance from the eye. It is not the beam divergence of the source (see Section 8.1 for criteria and Figure 14 for an illustration). *Unit:* radians (rad).

attenuation. The decrease in the power or energy as it passes through an absorbing or scattering medium.

authorized personnel. Individuals approved by management to operate, maintain, service, or install laser equipment.

average power (Φ). The total energy in an exposure or emission divided by the duration of that exposure or emission. *Unit:* watts (W).

aversion response. Closure of the eyelid, eye movement, pupillary constriction, or movement of the head to avoid an exposure to a noxious or bright light stimulant. In this standard, the aversion response to an exposure from a bright, visible, laser source is assumed to limit the exposure of a specific retinal area to 0.25 s or less.

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

beam diameter. The distance between diametrically opposed points in that cross section of a beam where the power or energy is 1/e (0.368) times that of the peak power or energy (see Figure B5). *Unit:* centimeters (cm).

beam divergence (ϕ). For purposes of this standard, divergence is the increase in the diameter of the laser beam with distance from the beam waist, based on the full angle at the point where the irradiance (or radiant exposure for pulsed lasers) is 1/e times the maximum value (see the upper left diagram in Figure 14 for an illustration of beam divergence). *Unit:* radians (rad).

4.4.3.6 Outdoor Control Measures (All Classes). All lasers or laser systems used outdoors shall meet the requirements found in ANSI Z136.6 (latest revision).

4.4.3.6.1 Use of Lasers in Navigable Airspace (All Classes). The FAA is responsible for regulating the use and efficient utilization of navigable airspace to ensure the safety of aircraft and the protection of people and property on the ground. Laser experiments or programs that will involve the use of lasers or laser systems in navigable airspace should be coordinated with the FAA (Washington, DC 20590, or any FAA regional office) and U.S. Space Command in the planning stages to ensure proper control of any attendant hazard to airborne and spaceborne personnel or equipment. Also refer to FAA order JO 7400.2 Part 6 Chapter 29 "Outdoor Laser Operations" and ANSI Z136.6 (latest revision). Laser light show demonstrations that use Class 3B or 4 laser systems to create visible open beams shall coordinate with the FDA prior to use (see Section 4.5.1).

4.4.3.7 Spectators and Laser Controlled Areas (Class 3B or 4). For both indoor and outdoor use, spectators should not be permitted within an LCA (see Sections 4.4.3.5.1 and 4.4.3.5.2) that contains a Class 3B laser or laser system, and spectators shall not be permitted within an LCA that contains a Class 4 laser or laser system unless

a) appropriate protective measures are taken,

b) appropriate approval from the supervisor has been obtained, and

c) the degree of hazard and avoidance procedure has been explained.

Laser demonstrations involving the general public shall be governed by the requirements of 4.5.1.

4.4.3.8 Alignment Procedures (Class 3B and 4). Alignment of Class 3B or 4 laser optical systems, for example, mirrors, lenses, and beam deflectors, shall be performed in such a manner that the primary beam, or a specular or diffuse reflection of a beam, does not expose the eye to a level above the applicable MPE (see Section 4.4.4.2.3.2 c).

NOTE—Laser incident reports have repeatedly shown that the highest risk for ocular hazard may exist during beam alignment procedures.

Written SOPs outlining alignment methods should be approved by the LSO for Class 3B and shall be approved for Class 4 lasers or laser systems. SOPs should be required for all classes of lasers or laser systems that contain embedded Class 3B lasers and shall be required for all classes of lasers or laser systems that contain embedded Class 4 lasers under conditions that would allow access during alignment procedures.

The use of lower power Class 1, 2, or 3R lasers with visible outputs for path simulation of higher power lasers is recommended for alignment of higher power Class 3B or 4 lasers and laser systems with visible or invisible outputs.

Alignments should be performed only by those who have received laser safety training. A Class 3B or 4 LCA shall be established. In addition, the following actions should be taken:

a) Wear LPE and protective clothing to the extent practicable.

b) Exclude unnecessary personnel from the LCA during alignment.

administratively required within the NHZ and their use enforced when engineering and other procedural and administrative controls are inadequate to eliminate potential exposure in excess of the applicable MPE. However, if analysis demonstrates that the Class 3R AEL will not be exceeded because of an extremely short NHZ, then the LSO may not require the administrative use of LPE. This could occur because of laser beam emission characteristics, for example, highly divergent beam, restrictions placed on the use of the laser or laser system, for example, limited open beam path, or other factors.

LPE are specifically designed to protect against a single wavelength, set of wavelengths, or band of wavelengths, and the eyewear used must be appropriate for the wavelength(s) of the laser(s) in use.

LPE is not required for Class 2 or Class 3R lasers or laser systems except in conditions where intentional long-term (> 0.25 s) direct viewing is required.

LPE may include goggles, face shields, spectacles, or prescription eyewear using special absorptive filter materials or reflective coatings, or a combination of both, to reduce the potential ocular exposure to or below the applicable MPE.

LPE shall be specifically selected to withstand either direct or diffusely scattered beams depending upon the anticipated circumstances of exposure. In this case, the protective filter shall exhibit a damage threshold for a specified exposure time; typically 10 seconds (see Appendix C). The eyewear shall be used in a manner so that the damage threshold is not exceeded in the worst case exposure scenario. Important in the selection of LPE is the factor of flammability (see ANSI Z87.1, latest revision).

Recent studies have indicated that existing laser eye protective filters, including polycarbonate, glass, interference, or hybrid filters, often exhibit nonlinear effects, for example, saturable absorption, that can reduce the OD (see ANSI Z136.7, latest revision) when exposed to ultrashort, for example, picosecond and femtosecond, pulse durations. Laser users should request test data from laser eyewear manufacturers.

4.4.4.2.2 Factors in Selecting Full Protection Eyewear. The following factors shall be considered when selecting the appropriate LPE to be used:

a) OD requirement of eyewear filters at laser output wavelength(s),

b) comfort and fit,

c) MPE (see Section 8),

d) need for prescription glasses,

e) wavelength(s) of laser output,

f) laser power and pulse energy,

g) potential for multiwavelength operation,

h) requirement for anti-fogging design or coatings,

i) exposure time criteria (see Section 4.4.4.2.3.2 and Table 3),

j) angular dependence of protection afforded (see Section 4.4.4.2.9.3),

g) Provide appropriate training, for example, CPR or electrical safety.

h) Avoid plugging one multi-outlet strip into a second multi-outlet strip (“daisy chain”).

i) Provide high voltage connectors and electrical panels that are “touch safe”, that is, properly insulated to prevent shock when touched.

j) Ensure that equipment designed for use in an equipment rack is used only when properly mounted in an appropriate equipment rack.

k) Avoid using extension cords as permanent wiring. Extension cords should only be plugged into an outlet while the device to which they provide power is actually operating.

7.2.2 Nonlaser Radiation (NLR).

7.2.2.1 Ionizing Radiation. Control measures shall be implemented in accordance with the provisions listed in applicable federal, for example, 21CFR 1020, state, or local codes and regulations to ensure protection from ionizing NLR arising from

a) x-ray collateral radiation generated by electronic components of the laser system, for example, high voltage vacuum tubes that are usually >15 kV, and LTIR from plasmas resulting from pulsed laser beams with a peak irradiance of the order of 10^{16} W cm^{-2} or higher that are focused on a target, and

b) plasma LTIR induced by extremely high power laser beams (> ~10^{18} W·cm^{-2}) incident on specifically designed targets resulting in acceleration of ions to produce ionizing radiation, particularly neutrons, that in turn may lead to activation (induced radioactivity) in materials surrounding the target.

LSOs needing additional assistance evaluating or controlling ionizing radiation sources should consult a health physicist.

7.2.2.2 Optical Radiation. UV and blue light NLR, for example, collateral radiation from laser discharge tubes and pump lamps, and LTIR plasma emissions, shall be suitably shielded so that personnel exposures are maintained within exposure limits specified by the ACGIH® *Threshold Limit Values (TLVs) for Chemical Substances and Physical Agents and Biological Exposure Indices*.

Special consideration should be given to protection of persons exposed to photosensitizing agents, for example, common drugs such as methotrexate, tricyclic antidepressants, amiodarone, and tetracycline and its congeners, where applicable. High levels of shorter wavelength UV radiation can produce significant amounts of ozone that shall be exhausted if concentrations would otherwise exceed recognized ozone exposure limits.

Visible and IR NLR should be controlled to within exposure limits specified by the ACGIH® *Threshold Limit Values (TLVs) for Chemical Substances and Physical Agents and Biological Exposure Indices.*

NOTE─Much of the optical radiation band, UV less than about 250 nm and IR greater than about 2500 nm, may be shielded with plastics such as polycarbonate and poly(methyl methacrylate)-type plastics. Additives (dyes) may be necessary for wavelengths between 250 nm and 2500 nm.

7.5 Laser and Laser Waste Disposal.

7.5.1 Laser Disposal. Laser users and LSOs shall ensure the safe and responsible disposition of lasers of all classes, especially Class 3B or 4 lasers and laser components. Recommended methods of laser disposal include

a) Turn the laser over to an external or internal organization delegated to dispose of lasers.
b) Return the laser or laser system to the original manufacturer, or to a vendor specializing in reselling used laser equipment.
c) Eliminate the possibility of activating the laser and laser system by removing all means by which it can be electrically activated. The laser may then be discarded. This method could have some landfill restrictions due to the presence of hazardous material in the laser components, such as mercury switches, oils, and organic dyes. Ensure compliance with the applicable hazardous waste disposal regulations.
d) Donate the laser to an organization, for example, academic institution, industrial company, or hospital, with a need for such a device. The donor shall ensure that the donated laser and laser system complies with all applicable product safety standards, such as the FLPPS, and adequate instructions for safe operation and maintenance is provided. The donor shall also verify that the receiving organization has a viable laser safety program for the class of laser being donated.

7.5.2 Laser Waste Disposal. Proper waste disposal of contaminated laser-related material, such as flue and smoke filters, organic dyes, and solvent solutions shall be handled in conformance with appropriate federal, state, and local guidelines.

7.6 References.

An extensive bibliography on NBH is available online on the z136.lia.org website under TSC-5 Committee Documents.

8. Maximum Permissible Exposure Criteria for Exposures of Eye and Skin

By definition, the MPE values are below known hazardous levels. Appendix E provides reference material on biological effects. Exposure to levels at the MPE value may be uncomfortable to view or feel upon the skin. Thus, it is good practice to maintain exposure levels sufficiently below the MPE to avoid discomfort.

NOTE—Visual interference effects can result from exposures to visible laser beams at levels below the MPE. These effects include temporary flashblindness, glare, and startle, and can create secondary hazards. These low-level effects are covered for nighttime laser use in FAA order JO 7400.2, Part 6 Chapter 29 "Outdoor Laser Operations" and ANSI Z136.6.

MPEs are expressed as radiant exposure or irradiance, both of which include an area in their units. Therefore, a limiting aperture or limiting cone angle shall be used for measurements or calculations with all MPEs. The limiting aperture is the maximum circular area over which irradiance or radiant exposure shall be averaged. See Section 3 and Table 10a for selection and retinal areas shall not exceed these limits within 48 hours. The exposure levels defined in Sections 8.1-8.2 shall also not be exceeded.

b) To protect against thermally induced retinal injury, the MPE for extended sources shall be calculated with a T_2 =200 s.

8.3.3 Anterior Segment in Maxwellian View. In the wavelength range 400 nm to 1400 nm, irradiation of large retinal areas, that is, "Maxwellian View," may result in high irradiances of the anterior segment of the eye. If the iris is not exposed, the irradiance of the cornea and crystalline lens within a 1 mm aperture shall not exceed $25 \cdot t^{-0.75}$ $W \cdot cm^{-2}$ for $t < 10$ s, and 4.0 $W \cdot cm^{-2}$ for $t > 10$ s. Exposure of the iris shall not exceed five times the MPEs of the skin (see Section 8.4 and Table 9). For hazard analysis of the iris, the limiting aperture for corneal exposures for wavelengths 1200 nm to 1400 nm (see Table 10a) shall be used for all wavelengths.

8.3.4 Repetitive Pulses. If the eye has a large pupil or is immobilized, the single-pulse MPE as determined from Section 8.2.3 shall be reduced by a factor of 2 if $C_p = 1$ and the number of pulses is 600 or greater (n ≥ 600 pulses).

8.4 MPE for Skin Exposure to a Laser Beam.

MPEs for skin exposure to a laser beam are given in Tables 9a, 9b, and 9c. These levels are for worst-case conditions and are based on the best available information.

8.4.1 MPE for Skin, Multiple-Pulse Exposures. For repetitive-pulsed lasers, the application of MPEs for skin exposure entails exposure of the skin shall not exceed the MPE based upon a single-pulse exposure (Section 8.2.3, Rule 1), and the average irradiance of the pulse train shall not exceed the MPE applicable for any pulse train, duration T up to T_{max} (Section 8.2.3, Rule 2). Rule 3 does not apply to skin exposure.

8.4.2 Large Area Exposures (Wavelengths Greater than 1400 nm). For beam cross-sectional areas between 100 cm^2 and 1000 cm^2 with diameters between 11.2 cm and 35.6 cm, the MPE for exposure durations exceeding 10 s is 10,000 mW/A_s, where A_s is the area of the exposed skin in cm^2. For exposed skin areas exceeding 1000 cm^2, the MPE is 10 $mW \cdot cm^{-2}$.

9. Measurements and Calculations

Guidance on laser safety measurements can be found in ANSI Z136.4. Measurements or calculations of laser beam parameters should be performed under the following circumstances:

a) when alterations to a system may have changed its classification,

b) when there is uncertainty in the laser beam parameters that determine OD requirements for laser eyewear,

c) to classify a laser or laser system when it has not been classified by the manufacturer in accordance with the) or IEC 60825-1 (see Appendix F), or

Table 4. Pulse Energy That Does Not Exceed the MPE for a Diffusely Reflected Beam

This table shows the maximum single pulse energy (in Joules) that does not exceed the MPE for a laser of

a) pulse duration 10 ps to 5 µs for wavelengths from 400 nm to 1050 nm, and
b) pulse duration 10 ps to 13 µs for wavelengths from 1050 nm to 1200 nm.

Beam Diameter (cm)	Pulse energy in Joules for viewing distance		
	r_1 = 20 cm	r_1 = 100 cm	r_1 = 1000 cm
0.1	0.001 × C_A	0.006 × C_A	0.63 × C_A
0.2	0.003 × C_A	0.008 × C_A	0.63 × C_A
0.3	0.008 × C_A	0.013 × C_A	0.63 × C_A
0.4	0.013 × C_A	0.017 × C_A	0.63 × C_A
0.5	0.021 × C_A	0.021 × C_A	0.63 × C_A
0.6	0.030 × C_A	0.030 × C_A	0.63 × C_A
0.7	0.041 × C_A	0.041 × C_A	0.63 × C_A
0.8	0.054 × C_A	0.054 × C_A	0.63 × C_A
0.9	0.068 × C_A	0.068 × C_A	0.63 × C_A
1.0	0.084 × C_A	0.084 × C_A	0.63 × C_A
1.5	0.19 × C_A	0.19 × C_A	0.63 × C_A
2.0	0.34 × C_A	0.34 × C_A	0.84 × C_A
2.5	0.52 × C_A	0.52 × C_A	1.0 × C_A
3.0	0.76 × C_A	0.75 × C_A	1.3 × C_A
3.5	1.0 × C_A	1.0 × C_A	1.5 × C_A
4.0	1.3 × C_A	1.3 × C_A	1.7 × C_A
4.5	1.7 × C_A	1.7 × C_A	1.9 × C_A
5.0	2.1 × C_A	2.1 × C_A	2.1 × C_A
6.0	3.0 × C_A	3.0 × C_A	3.0 × C_A
7.0	4.1 × C_A	4.1 × C_A	4.1 × C_A
8.0	5.4 × C_A	5.4 × C_A	5.4 × C_A
9.0	6.9 × C_A	6.8 × C_A	6.8 × C_A
10.0	8.5 × C_A	8.4 × C_A	8.4 × C_A

(Table 4 Continued on Next Page)

Table 12c. Control Measures for the Seven Laser Classes (cont.)

Personal Protective Equipment (PPE)	Classification						
	1	1M	2	2M	3R	3B	4
Laser Protective Eyewear (4.4.4.2)	—	—	—	—	—	X	X
Skin Protection (4.4.4.3)	—	—	—	—	—	•	•
Protective Clothing (4.4.4.3.1)	—	—	—	—	—	•	•

LEGEND: X Shall
• Should
— No requirement

Table 12d. Control Measures for the Seven Laser Classes (cont.)

Special Considerations and Warning Signs	Classification						
	1	1M	2	2M	3R	3B	4
Laser Optical Fiber Systems (4.5.2)	MPE	MPE	MPE	MPE	MPE	X	X
Laser Robotic/Automated Installations (4.5.3)	—	—	—	—	—	X	X
Laser Controlled Area Warning Signs and Equipment Labels (4.6)	—	—	—	—	—	X	X

LEGEND: X Shall
— No requirement
MPE Shall if MPE is exceeded
NHZ Nominal Hazard Zone analysis required

Figure 1c. Sample ANSI Z535.2 Compliant Class 4 Laser Controlled Area Danger Sign Format.

Figure 1d. ANSI Z535.2 Signal Words

Appendix A
Supplement to Section 1 – Laser Safety Programs

NOTE—The following material is an extension of section 1.3 and, as a normative Appendix, is an integral part of the standard.

A1. Laser Safety Officer (LSO)

A1.1 General.

The LSO is an individual designated by the employer with the authority and responsibility to effect the knowledgeable evaluation and control of laser hazards and to monitor and enforce the control of such hazards. The LSO shall have the authority to suspend, restrict, or terminate the operation of a laser system if they deem that the laser hazard controls are inadequate. For the laser safety program to be effective, the LSO must have sufficient authority to accompany the responsibility. In organizations that do not permit authority to reside with nonmanagement personnel, and the LSO is a nonmanagement position, the management shall provide protocols and reporting structure to ensure adequate enforcement authority.

The LSO may be designated from among personnel such as the radiation safety officer, industrial hygienist, safety engineer, laser specialist, laser operator, or user. The LSO may be a part-time position when the workload for an LSO does not require a full-time effort. In some instances, the designation of an LSO may not be required. Operation and maintenance of Class 1, 1M, 2, 2M, and 3R lasers and laser systems normally do not require the designation of an LSO. However, under some circumstances, it may be desirable to designate an LSO, for example, if service is performed on a laser system having an embedded Class 3B or 4 laser or laser system. In such instances, management may designate the service person requiring access to the embedded laser as the LSO. In any case, there shall be a designated LSO for all circumstances of operation, maintenance, and service of a Class 3B or 4 laser or laser system.

If necessary, a Deputy LSO (DLSO) shall be appointed by management or the LSO. The DLSO shall perform the functions of the LSO when the latter is not available. For institutions with multiple divisions or plant locations, a system of DLSOs may be required.

A1.2 LSO Specific Duties and Responsibilities.

a) **Accidents.** The LSO should develop a plan to respond to notifications of incidents of actual or suspected exposure to potentially harmful laser radiation. The plan should include the provision for medical assistance for the potentially exposed individual, provisions for investigation of the incident, and documentation for reporting the results of the investigation. If the LSO works for a laser manufacturer, be aware that the manufacturer is required to submit an Accidental Radiation Occurrence Report to the CDRH for events that result in "injurious or potentially injurious exposure of any person to electronic product radiation as a result of the manufacturing, testing, or use

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Appendix B
Calculations for Hazard Evaluation and Classification

B1. General

Calculations are not necessary for hazard evaluation and classification in many applications. In outdoor applications, however, and other specialized uses where eye exposure is contemplated, several types of calculations permit the important quantitative study of potential hazards.

a) Mathematical symbols used here are defined in B2.
b) MPE determination may require the use of formulae in B3.
c) Hazard classification methods are discussed in B4.
d) Formulae for computing beam irradiance and radiant exposure are contained in B5.
e) Formulae useful in hazard evaluation and calculating the NOHD and NHZ are listed in B6.
f) Methods for determining MPEs based on retinal hazards from both photochemical and thermal effects for extended visible laser sources are discussed in B7.
g) Formulae useful in determining adequate laser protective eyewear (LPE) or laser protective barriers are listed in B8.
h) Determination of extended-source sizes is discussed in B9.
i) Applicable references are contained in B10.
j) Figures B1 through B11 illustrate conditions of ocular exposure to laser radiation.
k) Figure B12 provides a laser analysis flowchart that can be used to aid in determining MPEs.

B2. Symbols

The following symbols are used in the formulae of this Appendix.

a = Diameter of emergent laser beam (cm).

α = Apparent angle subtended by a source at the location of the viewer (rad).

α_{max} = Apparent angle subtended by a source above which the thermal hazard is proportional to the radiance of the source (5 mrad to 100 mrad).

α_{min} = Apparent angle subtended by a source above which extended-source MPEs apply (1.5 mrad).

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Secretariat & Publisher

LIA™

12001 Research Parkway, Suite 210
Orlando, FL, USA
1-800-LASER-37
www.lia.org

ISBN 978-1-940168-29-6
9 781940 168296 90000>