

American National Standard

*American National Standard
for Safe Use of Optical Fiber
Communication Systems Utilizing
Laser Diode and LED Sources*



**Laser Institute
of America**
Laser Applications and Safety



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**American National Standard
for Safe Use of Optical Fiber
Communication Systems Utilizing
Laser Diode and LED Sources**

**Secretariat
Laser Institute of America**

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American National Standard

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Foreword (This introduction is not a normative part of ANSI Z136.2-2012, *American National Standard for Optical Fiber Communication Systems Utilizing Laser Diode and LED Sources*.)

In 1968, the American National Standards Institute (ANSI) approved the initiation of the Safe Use of Lasers Standards Project under the sponsorship of the Telephone Group.

Prior to 1985, Z136 standards were developed by ANSI Committee Z136 and submitted for approval and issuance as ANSI Z136 standards. Since 1985, Z136 standards are developed by the ANSI Accredited Standards Committee (ASC) Z136 for Safe Use of Lasers. A copy of the procedures for development of these standards can be obtained from the secretariat, Laser Institute of America, 13501 Ingenuity Drive, Suite 128, Orlando, FL 32826 or viewed at www.z136.org.

The present scope of ASC Z136 is to protect against hazards associated with the use of lasers and optically radiating diodes.

ASC Z136 is responsible for the development and maintenance of this standard. In addition to the consensus body, ASC Z136 is composed of standards subcommittees (SSC) and technical subcommittees (TSC) involved in Z136 standards development and an editorial working group (EWG). At the time of this printing, the following standards and technical subcommittees were active:

SSC-1	Safe Use of Lasers (parent document)
SSC-2	Safe Use of Lasers and LEDs in Telecommunications Applications
SSC-3	Safe Use of Lasers in Health Care
SSC-4	Measurements and Instrumentation
SSC-5	Safe Use of Lasers in Educational Institutions
SSC-6	Safe Use of Lasers Outdoors
SSC-7	Eyewear and Protective Barriers
SSC-8	Safe Use of Lasers in Research, Development, and Testing
SSC-9	Safe Use of Lasers in Manufacturing Environments
SSC-10	Safe Use of Lasers in Entertainment, Displays, and Exhibitions
TSC-1	Biological Effects and Medical Surveillance
TSC-2	Hazard Evaluation and Classification
TSC-4	Control Measures and Training
TSC-5	Non-Beam Hazards
TSC-7	Analysis and Applications
EWG	Editorial Working Group

The eight standards currently issued are:

ANSI Z136.1-2007, *American National Standard for Safe Use of Lasers* (replaces ANSI Z136.1-2000)

ANSI Z136.2-2012, *American National Standard for Safe Use of Optical Fiber Communication Systems Utilizing Laser Diode and LED Sources* (first edition)

ANSI Z136.3-2011, *American National Standard for Safe Use of Lasers in Health Care* (replaces ANSI Z136.3-2005, *American National Standard for Safe Use of Lasers in Health Care Facilities*)

ANSI Z136.4-2010, *American National Standard Recommended Practice for Laser Safety Measurements for Hazard Evaluation* (replaces ANSI Z136.4-2005)

ANSI Z136.5-2009, *American National Standard for Safe Use of Lasers in Educational Institutions* (replaces ANSI Z136.5-2000)

ANSI Z136.6-2005, *American National Standard for Safe Use of Lasers Outdoors* (replaces ANSI Z136.6-2000)

ANSI Z136.7-2008, *American National Standard for Testing and Labeling of Laser Protective Equipment* (first edition)

ANSI Z136.8-2012, *American National Standard for Safe Use of Lasers in Research, Development or Testing* (first edition)

This American National Standard provides guidance for the safe use, maintenance, service, and installation of optical communications systems utilizing laser diodes or light emitting diodes operating at wavelengths between 0.6 μm and 1 mm. Optical communication systems include end-to-end optical fiber based links, fixed terrestrial point-to-point free-space links, or a combination of both. This standard is intended to be used by those who assemble the end-to-end system and by service, maintenance, and other personnel who may come in contact with such systems where access is in uncontrolled, controlled and restricted locations. It provides detailed safety information for systems where optical energy may be accessible and where source parameters are uncertain or not under the control of the user. Control measures commensurate with the specific hazard level (optical fiber links) and access level (free-space links) are provided. Most evaluations can be carried out analytically and a number of representative examples of hazard evaluation are provided in the Appendixes.

It is expected that this standard will be periodically revised as new information and experience in the use of lasers are gained. Future revisions may have modified content and use of the most current document is highly recommended.

While there is considerable compatibility among existing laser safety standards, some requirements differ among state, federal, and international standards and regulations. These differences may have an effect on the particulars of the applicable control measures.

Occasionally questions may arise regarding the meaning or intent of portions of this standard as it relates to specific applications. When the need for an interpretation is brought to the attention of the secretariat, the secretariat will initiate action to prepare an appropriate response. Since ANSI Z136 standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, the secretariat is not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration. Requests for interpretations and suggestions for improvements of the standard are welcome. They should be sent to ASC Z136 Secretariat, Laser Institute of America, 13501 Ingenuity Drive, Suite 128, Orlando, FL 32826.

This standard was processed and approved for submittal to ANSI by ASC Z136. Committee approval of the standard does not necessarily imply that all members voted for its approval.

Robert Thomas, Committee Chair
Sheldon Zimmerman, Committee Vice-Chair
Ben Edwards, Committee Secretary

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(This notice is not a normative part of ANSI Z136.2-2012, *American National Standard for Optical Fiber Communication Systems Utilizing Laser Diode and LED Sources*.)

Z136 standards and recommended practices are developed through a consensus standards development process approved by the American National Standards Institute. The process brings together volunteers representing varied viewpoints and interests to achieve consensus on laser safety related issues. As secretariat to ASC Z136, the Laser Institute of America (LIA) administers the process and provides financial and clerical support to the committee.

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American National Standard for Safe Use of Optical Communications Systems Utilizing Laser Diodes and LED Sources

1. General

1.1 Scope

This standard addresses hazards and provides guidance for the safe use, maintenance, service, and installation (manufacturer) of optical communications systems (OCS) utilizing laser diodes or light emitting diodes (LED) operating at wavelengths between 0.6 μm and 1 mm and not intended for visual communications.¹ For purposes of this standard, OCS includes end-to-end optical fiber based links (optical fiber communications systems – OFCS), fixed terrestrial point-to-point free-space links (free space optical communications systems – FSOCS) or a combination of both.

Sections 3.4 and 4.3 of this standard apply only to systems or parts of systems where the radiant energy is confined within an optical fiber during intended use (OFCS); Sections 3.5 and 4.4 of this standard apply only to those open beam systems where the radiant energy is always available during intended use (FSOCS). As defined in this standard, FSOCS applies only to fixed, point-to-point terrestrial systems used for telecommunications purposes. For other free-space optical systems and applications, refer to ANSI Z136.6.

NOTE—LEDs are included in the scope of this standard for the following reasons: 1) The optical energy emitted by an LED (usually an edge-emitter) launched into an optical fiber results in a worst-case viewing condition approximately the same as if the source were a laser. 2) Although the spectral bandwidth of an LED is much larger than that of a laser, the spectral emission is still relatively narrow and the tables for the maximum permissible exposure (MPE) values and accessible emission limits (AEL) can still be used satisfactorily to provide conservative results.

1.2 Purpose

The purpose of this standard is to provide specific requirements for the safe use, service, operation, maintenance and installation of OCS, including OFCS and FSOCS. As such, it is intended to be used by those who assemble the end-to-end system (installation) and by service, maintenance, and other personnel who may come in contact with such systems where access is in uncontrolled, controlled and restricted locations. It provides detailed safety information for systems where optical energy may be accessible and where source parameters are uncertain or not under the control of the user.

NOTE—It is recognized that the user of this standard may fall into one or more of the following categories: manufacturer, installer, or service/installation and/or operating organization. Although the installer of the end-to-end system comprised of certified products, e.g., products certified in

¹ For consistency and because the unit micrometer (μm) is the preferred unit used throughout the optical communications field, μm will be used throughout this document.

accordance with the Federal Laser Product Performance Standard, could be considered the final “manufacturer,” the overall system is generally not considered to be the certified product.

This standard places the responsibility for certain product safety requirements, as well as requirements for providing appropriate information on how to use these systems safely, on the manufacture of the system and/or transmitters. The manufacturers and their products are subject to the requirements of the Federal Laser Product Performance Standard² (FLPPS); the safe deployment and use of these systems is the responsibility of the installation and/or operating organization. It places the responsibility for adherence to safety instructions during installation and service operations on the installation and service organizations as appropriate, and operation and maintenance functions on the operating organization.

1.3 Application

The objective of this standard is to provide reasonable and adequate guidance for the safe use, installation and maintenance of OCSs. A practical means for accomplishing this is to first determine the applicable *hazard level* and location type (for an OFCS) or the appropriate Class, location type and *access level* (for an FSOCS), and then specify appropriate controls.

NOTE—The hazard level of an OFCS, which is based on the *hazard class*, i.e., Class 1, 1M, 2, 2M, 3R, etc., was called “Service Group” in earlier editions of ANSI Z136.2 since most inadvertent exposures would be expected to occur during installation and service. In order to address exposures not related to service, e.g., a fiber break in an accessible location, and to harmonize with international standards such as IEC 60825-2,³ the term *Service Group* has been replaced with *Hazard Level*.

Application of this standard is as follows:

Determine the hazard level of the OFCS, or hazard class and access level of the FSOCS based on the potential for injury.

- a) Determine the location type(s) where the optical energy may be accessible.
- b) Apply the appropriate controls as specified for those hazard levels and location types (see Section 4).

The hazard levels associated with OFCS and the access levels for FSOCS in this standard are derived from the AELs described in ANSI Z136.1-2007⁴ and IEC 60825-1-2007⁵. This standard allows the use of automatic power reduction (APR) techniques and installation protection systems (IPS) to produce lower hazard levels and access levels based on the radiant power and speed of the APR or IPS. The shut-down times and measurement distances for APR systems used with OFCS are specified in IEC 60825-2 (2010) and are shown in Table 3.1.

NOTE—The hazard levels and access levels in this standard are analogous to the hazard classes, i.e., Class 1, 1M, 2, 2M, 3R and 3B. This approach is consistent with that of IEC- 60825-2 (2010)

² 21 CFR, Part 1040.10 – Laser products.

³ Safety of laser products - Part 2: Safety of optical fibre communication systems (OFCS).

⁴ When the year of publication is shown, the reference is to that specific standard; when the year of publication is not shown, it means the latest revision of that standard.

⁵ Safety of laser products - Part 1: Equipment classification and requirements.

and IEC-60825-12 (2004)⁶. In 1993, IEC 60825-2 (1993) introduced three types of locations for OFCS: *controlled*, e.g., buried cable or central offices; *restricted*, e.g., restricted office buildings; and *unrestricted*, e.g., unrestricted public areas. IEC 60825-2 (2007) does not permit access to Hazard Level 3B or Hazard Level 4 levels in unrestricted areas and does not permit access to Class 4 levels in any location. Since the concept of hazard level and access level incorporates the concept of using automatic power reduction, while the actual power existing within a fiber may be at Class 4 power levels, the hazard and access levels could be lower due to the APR or IPS. A fourth location type, *inaccessible*, is included in this standard for FSOCS.

Since the parameters used to define the different hazard levels for OFCS are wavelength, emitted optical power and beam divergence, devices such as OFCS lens connectors are also addressed provided the corresponding beam divergence can be determined.

A ready-for-use OCS certified for a specific class by the manufacturer as required by the FLPPS shall be considered as fulfilling the control requirements of this standard under conditions of normal operation.

NOTE—Often the labeling is associated only with the individual laser-containing components of the OCS, i.e., transmitters, regenerators and amplifiers. In these instances the OCS operating organization or supplier of the end-to-end system (turn-key) has the ultimate safety responsibility for the end-to-end engineered and assembled OCS.

The procedures in 1.3.2 for assigning the appropriate hazard class or hazard level where and when the OCS is being serviced or installed shall be used in the following instances:

- a) Where the laser or laser system hazard level/class and controls are not provided.
- b) Where an LED is used.
- c) Where the hazard level, access level or hazard class may change because of a change from the use intended by the manufacturer.
- d) Where engineering controls are added or deleted (see Section 4).

1.3.1 Hazard Classification (General). The basis of the hazard classification scheme in this standard is the ability of the direct (for OFCS, with or without a fiber attached) or reflected laser beam to cause biological damage to the eye or skin. The hazard classes, based on increasing risk, are as follows:

- a) **Class 1 laser systems:** Considered to be incapable of producing damaging radiation levels during operation and, therefore, exempt from any control measures or other forms of surveillance.
- b) **Class 1M laser systems:** Considered to be incapable of producing hazardous exposure conditions during normal operation unless the beam is viewed with an optical instrument such as eye-loupe (diverging beam) or telescope (collimated beam) and are, therefore, exempt from any control measures other than to prevent potentially hazardous optically aided viewing, and are exempt from other forms of surveillance.

⁶ Safety of laser products - Part 12: Safety of free space optical communication systems used for transmission of information.

- c) **Class 2 laser systems:** Emit in the visible portion of the spectrum (0.4 μm to 0.7 μm) and eye protection is normally afforded by aversion responses, including the blink reflex.
- d) **Class 2M laser systems:** Emit in the visible portion of the spectrum (0.4 μm to 0.7 μm) and eye protection is normally afforded by the aversion response (blink reflex) for unaided viewing, but are potentially hazardous if viewed with certain optical aids.
- e) **Class 3R laser systems:** Have reduced product safety requirements and represent a transitional zone between safe and hazardous laser products.
- f) **Class 3B laser systems:** May be hazardous under direct and specular reflection viewing conditions, but the diffuse reflection is usually not a hazard. Class 3B laser systems are normally not a fire hazard.
- g) **Class 4 (high power) laser systems:** Hazardous to the eye or skin from the direct beam, and sometimes from a diffuse reflection, and can also be a fire hazard.

The classification scheme relates specifically to the laser product and its potential hazard based on operating characteristics. However, the conditions under which the laser is used, the level of safety training of individuals using the laser, and other environmental and personnel factors are important considerations in determining the necessity for specific safety control measures. The responsibility for such judgments are assigned to persons with the requisite knowledge, authority and responsibility, namely the Laser Safety Officer (see 1.6).

Normally, the manufacturer of the OCS provides the hazard classification of the product based upon the FLPPS or IEC 60825-1. (For unique applications where the classification is not provided, refer to the latest revision of ANSI Z136.1.) During intended use the hazard class of an end-to-end optical fiber system is Class 1; FSOCS can readily be Class 1M or higher during normal operation.

Because of the unique characteristics of OFCS and FSOCS, for practical purposes hazard level (OFCS) and access level (FSOCS) are used to characterize the risk associated with each of these systems.

1.3.2 Hazard Level (OFCS). OFCS are designed to operate normally as Class 1 systems with the laser energy contained within the optical fiber(s) during intended use. However, there may be a risk of exposure above the MPE during installation and service of such systems or in the event of a fiber disconnect or break. Because the radiant energy emitted from an optical fiber is usually divergent, the risk for injury is different from that of a conventional laser operating at the same optical power and wavelength. To address this difference, the basic classification scheme in ANSI Z136.1 has been augmented by the establishment of system classification in terms of hazard levels. Specifically, OFCS, or portions thereof, shall be assigned one or more of seven hazard levels based on system parameters and accessibility. The seven hazard levels are Hazard Level 1, 1M, 2, 2M, 3R, 3B and 4, and are defined in Section 2.

Furthermore, this standard allows the use of APR techniques to produce a lower hazard level based on the power in the fiber and the speed of the APR. APR may be used in order to classify an OFCS or portion of an OFCS at a lower hazard level than the power of the laser/LED transmitter would otherwise permit. This is important when the hazard level of the internal

optical transmitters of a system may put a limitation on where that system may be deployed (see 3.4.2.4).

1.3.2.1 OFCS Utilizing Laser Diodes. The emission pattern of an optical fiber connected to a diode laser or LED is highly divergent, unlike that of a conventional laser, unless lens connectors are used. Therefore, the beam irradiance (hence any risk for eye injury) decreases rapidly with distance from the end of the fiber or output connector. (See Figures A.5 through A.7 in Appendix A for examples of safe viewing distances from the end of typical optical fibers or connectors, i.e., the distance to the point at which the MPE and the beam irradiance averaged over the limiting aperture are equal.) Because of the beam divergence, inadvertent viewing of the accessible emission from a disconnected or unterminated energized fiber with the unaided eye at distances greater than 10 cm from Hazard Level 1M, 2M, or 3R OFCS normally will not cause eye injury but damage may occur under optically-aided viewing conditions. Eye injury may also occur for unaided viewing of the accessible emission from Hazard Level 3B OFCS, especially when lens connectors (which by design decrease the divergence inherent in the optical fiber) are used.

OFCS have limitations imposed by this standard that are dependent on the location type(s) in which they are installed. Product classification and hazard level restrictions are summarized in Table 3.2 (see Section 3).

1.3.2.2 OFCS Utilizing LEDs. OFCS that utilize LEDs generally emit non-coherent radiant energy at wavelengths greater than 0.7 μm and power levels considerably less than laser diode sources. Since the potential risk of injury is determined by the output characteristics of the OFCS, including power, wavelength and beam divergence, the potential risk for injury is, therefore, generally less for an LED system than for a similar system utilizing laser diodes. However, for purposes of uniformity, all control measures commensurate with a specific hazard level apply to both laser diode systems and LED systems.

1.3.3 Access Level (FSOCS). FSOCS have limitations imposed by this standard that are dependent on the location type(s) in which they are installed, i.e., because of the nature of FSOCS links, the relative hazard can vary with location in or near the beam path(s). For this reason, the concept of access level is introduced to describe the hazard from potential exposure at a particular location. Because this standard deals with human exposure, the access levels are based upon conditions of potential exposure relative to the applicable MPE and worst-case exposure concepts embodied in the AELs. The access levels are derived from the AELs described in ANSI Z136.1-2007 and IEC 60825-1 (2007), e.g., Access Levels 1 and 1M are based upon the AELs for Class 1 and 1M, respectively, etc., and are based on the level of optical radiation that could become accessible in reasonably foreseeable circumstances, e.g., walking into an open beam path. The seven access levels used for FSOCS, i.e., Access Levels 1, 1M, 2, 2M, 3R, 3B and 4, are defined in Section 2.

NOTE—The term *reasonably foreseeable* relates to the determination whether a particular location is to be treated as inaccessible space or another location type.

Product classification and access level restrictions by location type are summarized in Table 3.3 (see Section 3). Note that this standard allows the use of APR and IPS to produce a lower hazard level based on optical power and the speed of the APR and/or IPS.

1.4 Procedure for Using this Standard

The recommended stepwise procedure for using this standard is as follows:

- a) **Determine the type of OCS.** Determine whether or not a free-space link exists within the OCS. If not, only the requirements applicable to OFCS apply.
- b) **Determine the Hazard Level (OFCS) and/or Access Level (FSOCS) of the complete system.** The capability of radiant energy to cause injury is based on the hazard class of the complete system under normal operating conditions and the hazard evaluation of the components form the basis of determining the hazard level and/or access level of the OCS.
- c) **Determine the applicable location types.** This will determine the degree of controls required for each of the hazard levels or access levels. There are four location types (see Sections 2 and 3):
 - 1) **Unrestricted location:** Access to the transmitting and receiving equipment, the protective housing (enclosure), or to an open beam is unrestricted and beam levels do not exceed the Class 1 AELs. Examples include domestic premises and premises open to the public.
 - 2) **Restricted location:** Access to the protective housing (enclosure) or an open beam exceeding Class 1 AELs is not accessible to the public. Examples include secured areas within industrial areas not open to the public, overhead cables and fiber optic cable drops to a building, and FSOCS transmitters in secured areas within buildings or rooftops.
 - 3) **Controlled location:** Access to the enclosure (protective housing) or an open beam at levels exceeding the Class 1 AELs is controlled and is accessible only to authorized persons who have received adequate training in laser safety and servicing of the system.
 - 4) **Inaccessible location (FSOCS):** Locations where an open beam exceeds the Class 1 AELs and where a person normally cannot be located, e.g., for FSOCS, in open space at a height of more than 6 m above the ground.
- d) **Determine and apply the appropriate control measures.** The total hazard evaluation of the OCS influences the type and application of control measures. Based on the hazard evaluation (see Section 3), apply the appropriate control measures (see Section 4).

The appropriate hazard or access level of the complete operational network should be determined, including FSOCS links, consisting of at least a transmitter, receiver, cabling that may also include switching devices, optical amplifiers, pump lasers for fiber amplifiers, etc., using the manufacturer's specifications for the components containing lasers or LEDs. Note that in order to do this the output specifications of the components containing lasers or LEDs must be provided in radiometric units of watts (W), milliwatts (mW), microwatts (μ W) or decibels referenced to 1 mW (dBm). If the laser-containing components of the system have been certified in accordance with the provisions of the FLPPS or IEC 60825-1, information on wavelength, power output and beam divergence should be included in the manufacturer-supplied user manual. If this information is not available, the measurement methods described

in Section 9 and ANSI Z136.4, and the hazard evaluation and classification descriptions given in Section 3 should be used.

For quantitative evaluation of the potential hazard associated with a given OCS, Sections 8 and 9 should be consulted. To use the MPE values in Section 8, first determine whether or not the MPE values for an extended (large) source, as given in 8.1, should be used, e.g., for the case where a number of fibers are arranged side-by-side in a ribbon or fixed in a pattern called an array. Table 5a can be used for default values as the MPE values listed are worst-case. Table 5b provides relaxed MPE values associated with the effects of extended-source viewing. (See Figures A.1 and A.2 in Appendix A for illustrated viewing conditions, Figure A.3 for the measurement arrangement used for hazard level classification and Figure A.4 for the measurement arrangement for determining the angular subtense of an extended source for purposes of determining correction factor C_E .)

NOTE—The hazard from broken, i.e., not cleaved or connectorized, fiber bundles and ribbon cable does not generally increase beyond the hazard of the worst-case fiber in the bundle.

1.5 Responsibilities

1.5.1 OCS Installation/Operating Organization. The installation or operating organization of the telecommunication service provider has the ultimate responsibility for the installation, service, maintenance and safe use of the end-to-end OCS. This includes, especially, the following:

- a) Ensuring that the equipment classification, access or hazard level requirements, and installation conditions from Tables 3.1, 3.2 and 3.3 of Section 3 are satisfied for those location types and access or hazard levels.
- b) Ensuring that installation, maintenance and service are performed only by an organization with the capability of satisfying the requirements of Sections 4.1 and 4.2.
- c) Identifying the location type at all portions of the entire transmission path of the OCS, including beam spillover outside the receiver collection area, and partial reflections from adjacent and nearby windows, where people may have access to optical radiation from an FSOCS.

1.6 Laser Safety Officer (LSO)

Major responsibility for situations that require informed judgments by responsible persons is assigned to a person with the requisite authority and responsibility, namely the Laser Safety Officer (LSO). Because of the nature of Class 1M FSOCS, when the knowledgeable evaluation of potentially hazardous optically aided viewing conditions has been performed by the manufacturer and installer, an LSO is not required; however, an individual sufficiently trained to safely install the specific FSOCS, i.e., a safety-qualified FSOCS installer, is normally assigned the responsibility for site evaluation and proper installation.

Normally, an LSO is not required for OFCS operations, as the OFCS would be Class 1 during intended use. However, an installation/servicing organization shall have an LSO if Class 3B or Class 4 levels are encountered by service personnel during routine service procedures.

Likewise, an LSO may be required for servicing/installing FSOCS where Class 3B or Class 4 levels of radiation become accessible.

1.6.1 Safety-Qualified Installer. A safety-qualified OCS installer is an individual who has been sufficiently trained to safely install the specific OCS. In order to ensure safe operation and installation, Hazard Level 1M and higher OFCS should be installed and serviced by a safety-qualified OFCS installer; Class 1M and higher FSOCS should be installed by a safety-qualified FSOCS installer.

2. Definitions

The definitions of the terms listed below are based on a pragmatic rather than a basic approach. The terms defined are therefore limited to those actually used in this standard and its appendixes and are in no way intended to constitute a dictionary of terms used in the OCS field as a whole.

access level (FSOCS). The potential hazard at any accessible position associated with an FSOCS installation based on the level of optical radiation that could become accessible in reasonably foreseeable circumstances during operation, e.g., walking into an open beam path. The access level is closely related to the laser classification defined in ANSI Z136.1 and IEC 60825-1.

NOTE 1—Reasonably foreseeable relates to the determination whether a particular location is to be treated as inaccessible space or as another location type, e.g., controlled, restricted or unrestricted.

NOTE 2—Practically speaking, it takes 2 or more seconds to fully align an optical aid with a beam (which might occur in an unrestricted location), and this delay is incorporated into the method for determining access level.

Access Level 1 (FSOCS). The level for which, under reasonably foreseeable circumstances, human access to laser radiation in excess of the accessible emission limits (AEL) of Class 1 for the applicable wavelengths and emission duration will not occur.

Access Level 1M (FSOCS). The level for which, under reasonably foreseeable circumstances, human access to laser radiation in excess of the accessible emission limits (AEL) of Class 1M for the applicable wavelengths and emission duration will not occur.

NOTE—If the applicable limit of Access Level 1M is larger than the limit of Class 3R and less than the limit of Class 3B, Access Level 1M is allocated.

Access Level 2 (FSOCS). The level for which, under reasonably foreseeable circumstances, human access to laser radiation in excess of the accessible emission limits (AEL) of Class 2 for the applicable wavelengths and emission duration will not occur.

Access Level 2M (FSOCS). The level for which, under reasonably foreseeable circumstances, human access to laser radiation in excess of the accessible emission limits (AEL) of Class 2M for the applicable wavelengths and emission duration will not occur.

NOTE—If the applicable limit of Access Level 2M is larger than the limit of Class 3R and less than the limit of Class 3B, Access Level 2M is allocated.

Access Level 3R (FSOCS). The level for which, under reasonably foreseeable circumstances, human access to laser radiation in excess of the accessible emission limits (AEL) of Class 3R for the applicable wavelengths and emission duration will not occur.

NOTE—If the applicable limit of Access Level 1M or 2M is larger than the limit of Class 3R and less than the limit of Class 3B, Access Level 1M or 2M is allocated.

Access Level 3B (FSOCS). The level for which, under reasonably foreseeable circumstances, human access to laser radiation in excess of the accessible emission limits (AEL) of Class 3B for the applicable wavelengths and emission duration will not occur.

Access Level 4 (FSOCS). The level for which, under reasonably foreseeable circumstances, human access to laser radiation in excess of the accessible emission limits (AEL) of Class 3B for the applicable wavelengths and emission duration may occur.

accessible emission limits (AEL). The maximum accessible emission level (power or energy) permitted within a particular class or hazard level.

accessible optical radiation. Optical radiation to which the human eye or skin may be exposed for the condition (use, maintenance, installation, or service) specified.

alpha max. The angular subtense of an extended source beyond which additional subtense does not contribute to the hazard and need not be considered. *Symbol:* $\alpha_{\max}$

alpha min. The angular subtense of a source below which the source can be effectively considered as a point source. The value of alpha min is 1.5 mrad. *Symbol:* $\alpha_{\min}$

aperture efficiency (η). The ratio of the maximum amount of energy coupled through a specified aperture to the amount of energy in the beam of an optical source located at a specified distance l from the source:

$$\eta = \left[1 - e^{-\left(\frac{d_0}{D_L}\right)^2} \right]$$

where d_0 and D_L are the diameter of the aperture and diameter of the beam at distance l , respectively.

apparent visual angle. The angular subtense (α) of the source as calculated from source size and distance from the eye.

NOTE—The apparent visual angle is not the beam divergence of the source.

authorized personnel. Individuals approved by management to install or service an OCS.

automatic power reduction (APR). A feature of a transmitter of an OCS, provided by the system equipment manufacturer, by which the accessible power in the nominal hazard zone (NHZ) or extended NHZ (ENHZ) is reduced to a specified value within a specified time, whenever there is an event that could result in human exposure to optical radiation above the maximum permissible exposure (MPE), e.g., by a person entering the NHZ or ENHZ as applicable. This feature may be used by the transmitter manufacturer to determine the classification.

beacon. An optical source whose function is to aid in pointing or aligning an optical system.

beamwidth (beam diameter). The distance between diametrically opposed points in the cross-section of a beam where the power per unit area is 1/e times that of the peak power per unit area.

For a multimode fiber, the beamwidth (D_L) is defined as:

$$D_L = \frac{2l \tan(\sin^{-1} NA)}{1.7}$$

where l is the distance from the end of the fiber and NA is the numerical aperture measured at the 5%-of-peak irradiance points.

NOTE 1—The numerical aperture (NA) is, by convention, defined at the 5%-of-peak irradiance points. To calculate the axial beam irradiance of a Gaussian beam, convention dictates that the beam cross-sectional area at the 1/e points must be used. The constant 1.7 in the first expression accounts for this difference.

The beam diameter of a single-mode fiber with a Gaussian beam profile is given by

$$D_L = \frac{2\sqrt{2} l \lambda}{\pi \omega_0}$$

where ω_0 is the mode-field diameter of the fiber and λ is the wavelength.

Where concern exists that the beam may not be Gaussian, or wavelengths other than the intended wavelengths are used, the more conservative expression below should be used.

$$D_L = \frac{2l\lambda}{\pi \omega_0}$$

NOTE 2—The above equation has been determined empirically from the results of beam profile measurements of the emission patterns from optical fibers, which in many instances have been found to have a “flat top” or approximately rectangular beam cross-section.

beam divergence. For beams that are circular or nearly circular in cross section, the beam divergence is the angle subtended by the far-field beam diameter. For beams that are not circular or nearly circular in cross section, the beam divergence is the far-field angle subtended by two diametrically opposed points in a plane perpendicular to the optical axis, at which points the irradiance is a specified fraction e.g., 1/e (36.8%), of the beam’s peak irradiance. Generally, only the maximum and minimum beam divergence (corresponding to the major and minor diameters of the far-field irradiance) need to be specified. The beam divergence (ϕ) of a multi-mode fiber is given by

$$\phi = \frac{2 \tan(\sin^{-1} NA)}{1.7} \approx \frac{2NA}{1.7}$$

where NA is the numerical aperture, measured at the 5%-of-peak irradiance points.

NOTE 1—The numerical aperture (NA) is, by convention, defined at the 5%-of-peak irradiance points. To calculate the axial beam irradiance of a Gaussian beam, convention dictates that the beam cross-sectional area at the 1/e points must be used. The constant 1.7 in the first expression accounts for this difference.

The corresponding beam divergence of a single-mode fiber with a Gaussian beam profile is given by

$$\phi = \frac{2\sqrt{2} \lambda}{\pi \omega_0}$$

where ω_0 is the mode-field diameter and λ is the wavelength.

Note that when the core diameter is substituted for the mode field diameter, or when concern exists that the beam may not be Gaussian, or wavelengths other than the intended wavelengths are used, the more conservative expression below should be used.

$$\phi = \frac{2\lambda}{\pi\omega_0}$$

NOTE 2—The above equation has been determined empirically from the results of beam profile measurements of the emission patterns from optical fibers, which in many instances have been found to have an approximately rectangular beam profile.

C_A. Correction factor that increases the MPE in the near infrared (IR-A) spectral band (0.7 μm - 1.4 μm) based upon reduced absorption properties of melanin pigment granules found in the skin and in the retinal pigment epithelium.

C_C. Correction factor that increases the MPE for ocular exposure because of pre-retinal absorption of radiant energy in the spectral region between 1.15 μm and 1.4 μm.

C_E. Correction factor used for calculating the extended source MPE for the eye from the point source MPE when the laser source subtends a visual angle exceeding α_{min}.

C_P. Correction factor that reduces the MPE for repetitive-pulse exposure of the eye.

cladding. The dielectric material surrounding the core of an optical fiber. By design, the cladding has a lower refractive index than the core.

communication system. *See:* **optical communications system.**

Condition 1. Pertains to optically aided viewing of collimated beams through telescopes or binoculars.

Condition 2. Pertains to optically aided viewing of sources with highly divergent beams through magnifiers or eye loupes or unaided viewing with or without strong accommodation.

NOTE—Condition 2 has slightly different measurement conditions in IEC 60825-1.

controlled location. *See:* **location with controlled access.**

control measure. For purposes of this standard, a means to mitigate potential hazards associated with the installation, service and maintenance of optical communications systems. Control measures can be divided into three groups: engineering, administrative (procedural) and personal protective equipment.

core. The central region of an optical waveguide through which optical energy is transmitted. By design, the core has a higher refractive index than the cladding.

critical frequency. The pulse repetition frequency above which the laser or LED output is considered continuous wave (CW). For example, for a short unintentional exposure (0.25 s to 10 s) to nanosecond (or longer) pulses, the critical frequency is 55 kHz for wavelengths between 0.4 μm and 1.05 μm, and 22 kHz for wavelengths between 1.05 μm and 1.4 μm.

dBm. A logarithmic expression of radiant power referenced to one milliwatt. dBm is defined as

$$P(\text{dBm}) = 10 \log_{10} \frac{P(\text{mW})}{1 \text{ mW}}$$

Thus 0 dBm = 1 mW; -10 dBm = 0.1 mW; 23 dBm = 200 mW; etc.

diffuse reflection. Change of the spatial distribution of a beam of radiation when it is reflected in many directions by a surface or by a medium.

embedded laser. An enclosed laser that has a higher classification than the laser system in which it is incorporated, where the system's lower classification is appropriate due to the engineering features limiting accessible emission.

extended source. A source of optical radiation with an angular subtense at the cornea larger than $\alpha_{\min}$. An example of an extended source would be a group of fibers arranged in a linear or two-dimensional array.

end-to-end system. An OCS that is comprised of at least one transmitter, one receiver and any peripheral hardware necessary for the effective transfer of data along the transmission path from one location to another. The entire end-to-end system may be an OFCS or it may contain FSOCS links.

eye-safe laser. A Class 1 laser product.

NOTE—Because of the frequent misuse of the term “eye-safe wavelength” to mean “retina-safe”, e.g., at 1.5 μm to 1.8 μm , and “eye-safe laser” to refer to a laser emitting at wavelengths outside the retinal-hazard region, the term “eye-safe” can be a misnomer. Hence, the use of the term “eye-safe laser” is discouraged.

fiber optics. The branch of optical technology concerned with the transmission of radiant energy through fibers made of transparent materials such as glass, fused silica, or plastic.

NOTE—Communication applications of fiber optics employ flexible fibers. Either a single discrete fiber or a non-spatially aligned fiber bundle may be used for each information channel. Such fibers are often referred to as “optical waveguides” to differentiate them from fibers employed in applications other than communications.

free space optical communications system (FSOCS). An installed or temporarily mounted, through-the-air system typically used for, or intended or promoted for voice, data or multimedia communications and/or control purposes via the use of modulated optical radiation produced by a laser or LED. “Free space” means indoor and outdoor optical wireless applications with both non-directed and directed transmission. Emitting and detecting assemblies may or may not be separated.

graded index profile (fiber). Any refractive index profile that varies with core radius (as distinguished from a step-index profile).

hazard level (OFCS). The level of a potential hazard that could become accessible during installation and service or in the event of a fault such as a fiber break. Hazard level is used for OFCS hazard assessment and control measures and is closely related to the laser classification in ANSI Z136.1 and IEC 60825-1.

Hazard Level 1 (OFCS). Safe under reasonably foreseeable conditions including the use of optical instruments for intrabeam viewing.

Hazard Level 1M (OFCS). Safe under reasonably foreseeable conditions but may be hazardous if optics are used for viewing the beam. Hazard Level 1M exceeds the accessible emission limit

(AEL) for Hazard Level 1 but does not exceed the AEL for hazard Level 3B. The irradiance at 100 mm from a Hazard Level 1M system will not exceed the MPE.

Hazard Level 2 (OFCS). Applies to the visible region (for purposes of this standard 0.6 μm to 0.7 μm) where eye protection is normally afforded by aversion responses including the blink reflex. This reaction may be expected to provide adequate protection under reasonably foreseeable condition of operation including the use of optical instruments for intrabeam viewing.

Hazard Level 2M (OFCS). Applies to the visible region (for purposes of this standard 0.6 μm to 0.7 μm) where eye protection is normally afforded by aversion responses. However, the output may be hazardous if optics are used to view the beam. For measurement purposes, optical components are placed within 100 mm of the source to concentrate the beam.

Hazard Level 3R (OFCS). Potentially hazardous for direct intrabeam viewing but the risk is lower than for Hazard Level 3B. The AEL is within five times the AEL for Hazard Level 2 for the visible region and within five times hazard Class 1 for other wavelengths.

NOTE—For highly divergent beams such as found in OFCS, Hazard Level 1M and 2M may have higher measured energy and power than Hazard Level 3R. For such conditions, an assignment of Hazard Level 1M or 2M is appropriate.

Hazard Level 3B (OFCS). Potentially hazardous when direct intrabeam viewing occurs. Viewing diffuse reflections is not hazardous.

Hazard Level 4 (OFCS). Potentially hazardous when direct intrabeam viewing occurs and capable of producing hazardous diffuse reflections. Hazard Level 4 emission may cause skin injuries and may constitute a fire hazard. Installation, service and maintenance of Hazard Level 4 systems requires extreme caution.

NOTE—Hazard Level 4 systems are not permitted under IEC 60825-2.

infrared. In this standard, the region of the electromagnetic spectrum between the long-wavelength extreme of the visible spectrum (0.7 μm) and the shortest microwaves (about 1 mm).

NOTE—Practical considerations limit the infrared wavelength region for OCS to 0.7 μm to 2.6 μm .

installation. Placement and connection of an OCS to enable intended operation. Installation includes connection and disconnection of optical connectors.

installation organization; installer. An organization or individual who is responsible for the installation of an OCS. A safety-qualified FSOCS or OFCS installer, for example, is an individual who is sufficiently trained to safely install the specific system.

installation protection system (IPS). A feature of an FSOCS installation, provided by the installation organization or operating organization, that has the following functions: (1) detect human entry into the accessible volume of either the NHZ for restricted or controlled locations or the ENHZ for an unrestricted location, and; (2) reduce the accessible power of the laser to a specified level within a specified time once such entry is detected.

integrated radiance. The integral of the radiance over the exposure duration, expressed in joules-per-centimeter-squared per-steradian ($\text{J cm}^{-2} \text{sr}^{-1}$).

intrabeam viewing. Viewing the source from within the beam.

irradiance. Radiant power incident per unit area upon a surface, expressed in watts-per centimeter-squared ($\text{W} \cdot \text{cm}^{-2}$). *Symbol:* ***E***

NOTE—The terms *power density* and *fluence rate* are sometimes used as synonyms for irradiance, although these terms have slightly different technical meanings.

laser. An acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation, i.e., a device that produces radiant energy predominantly by stimulated emission. Laser radiation generally exhibits a high degree of coherence.

laser diode. A laser employing a forward-biased semiconductor junction as the active medium. *Syn:* **injection laser, semiconductor laser.**

laser safety officer (LSO). One who has authority and responsibility to monitor and enforce the control of laser hazards and effect the knowledgeable evaluation and control of laser hazards.

lens connector. A connector that by design decreases the divergence inherent in the optical fiber. Because of the decreased divergence, the nominal hazard zone (NHZ) associated with lens connectors may be considerably greater than that of a conventional connector.

light emitting diode (LED). A p-n junction semiconductor device that can be made to produce electromagnetic radiation, in the wavelength range from 0.18 μm to 1 mm, by radiative recombination in the semiconductor.

limiting angular subtense. *See:* **alpha min.**

limiting aperture. The diameter of a circle over which irradiance or radiant exposure is averaged for purposes of hazard evaluation and classification. *Symbol:* ***d₀***

location type. A position or site occupied or potentially available for occupancy characterized in terms of access to laser energy.

There are four location types for FSOCS and three location types for OFCS:

- a) **location with unrestricted access; unrestricted location (FSOCS, OFCS).** A location where access to the transmitting/receiving equipment and open beam is not limited (accessible to the general public).
- b) **location with restricted access; restricted location (FSOCS, OFCS).** A location that is normally inaccessible to the general public (including workers, visitors, and residents in the immediate vicinity) by means of any administrative or engineering controls, e.g., protective housing, but that is accessible to authorized personnel that may not have laser safety training, e.g., maintenance or service personnel including window cleaners in exterior locations.
- c) **location with controlled access; controlled location (FSOCS, OFCS).** A location where the occupancy and activity of those within is subject to control and supervision, i.e., where access to the enclosure (protective housing) is controlled and is accessible only to authorized persons who have received adequate training in laser safety and servicing of the system. As an example, engineering or administrative controls may be introduced to make it inaccessible except to authorized trained personnel. A *laser controlled location* is where the personnel have been trained in laser safety and are authorized to service, install, maintain or operate the laser system.

- d) **location of inaccessible space; inaccessible space (FSOCS).** A volume where a person cannot normally be located. All open space that is neither an unrestricted, restricted nor controlled location, i.e., space that has a horizontal spacing more than 2.5 meters from any unrestricted location and is both greater than 6 meters above a surface in any unrestricted location, and more than 3 meters above a surface in any restricted location. Inaccessible space may be entered by, for example, aircraft.

maintenance. Performance of those adjustments or procedures specified in user information provided by the manufacturer of the FSOCS or OFCS that are to be performed by the user to ensure the intended performance of the product. It does not include *operation* or *service* as defined in this section.

manufacturer. For purposes of this standard, an organization or individual who makes, assembles or installs optical devices and other components for the construction or modification of an OCS.

maximum permissible exposure (MPE). The level of laser or LED radiation, associated with OCS, to which an unprotected person may be exposed without hazardous effect or adverse biological changes in the eye or skin.

NOTE—The MPEs for the eye, detailed in Section 8, are consistent with the MPEs in ANSI Z136.1 and IEC 60825-1.

minimum viewing distance. The minimum distance at which the eye can produce a focused image of a diffuse source, usually assumed to be 10 cm. *See:* **nominal ocular hazard distance, nominal hazard zone.**

mode-field diameter. The diameter of the single-mode irradiance distribution in a single-mode fiber measured at the $1/e^2$ -of-peak irradiance points. For practical purposes, the single-mode fiber core diameter may be used when the value of the mode field diameter is unavailable but a conservative estimate for beam divergence is necessary. The mode-field diameter is expressed in micrometers (μm). *Symbol:* ω_0 *See:* **beam divergence, beamwidth.**

nominal hazard zone (NHZ), extended nominal hazard zone (ENHZ). The NHZ is the space within which the level of the direct, reflected or scattered radiation may exceed the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the applicable MPE. The ENHZ is the space within which, when viewed directly or when viewed with optical aids, the level of the direct, reflected or scattered radiation exceeds the applicable MPE. Exposure levels outside the boundary of the ENHZ are below the applicable MPE when optical aids are used.

NOTE—The NHZ and ENHZ are determined prior to activation of any IPS or APR systems unless the APR is used for classification under the conditions of this standard.

nominal ocular hazard distance (NOHD). The distance along the axis of the unobstructed beam from a laser, fiber end or connector to the human eye beyond which the irradiance or radiant exposure, during installation or service, is not expected to exceed the appropriate MPE.

non-beam hazards (NBH). A class of hazards that result from factors other than direct human exposure to a laser beam.

numerical aperture (NA).

- a) The sine of one half of the vertex angle of the largest cone of meridional rays that can enter or leave an optical system or element, multiplied by the refractive index of the

medium in which the vertex of the cone is located. Generally measured with respect to an object or image point and varies as that point is moved.

- b) For an optical fiber in which the refractive index decreases monotonically from n_1 on axis to n_2 in the cladding, the numerical aperture is given by

$$NA = \sqrt{n_1^2 - n_2^2}.$$

- c) For purposes of this standard, the numerical aperture is measured at the 5%-of-peak irradiance points.

NOTE—Colloquially, NA is the sine of the radiation or acceptance angle of an optical fiber multiplied by the refractive index of the material in contact with the exit or entrance face. This usage is approximate and imprecise, but is often encountered.

operating organization; operator. Organization or individual who is responsible for the operation and maintenance of an OCS.

operation. The performance of the OCS over the full range of its functions. It does not include *installation, maintenance* or *service* as defined in this section.

optical amplifier. A device that may be optically pumped with a laser, or lasers, of the appropriate wavelength to produce stimulated emission at a specific wavelength and, hence, amplification at that wavelength.

optical cable. A fiber, multiple fibers or fiber bundle in a structure fabricated to meet optical, mechanical and environmental specifications. *Syn.* **optical fiber cable.**

optical cable assembly. An optical cable that is terminated with a connector.

optical communications system (OCS). An installed system used for the transmission of voice, data or multimedia communications and/or control purposes via the use of modulated optical radiation produced by a laser or LED. OCS includes end-to-end optical fiber based links (OFCS), fixed or temporarily-mounted terrestrial point-to-point free-space links (FSOCS) or a combination of both.

optical communications system transmitter. An optical transmitter emitting radiant energy into an optical fiber (OFCS) or into free space (FSOCS).

optical density. Logarithm to the base ten of the reciprocal of the transmittance.

$$OD = -\log_{10}\tau_{\lambda},$$

where τ_{λ} is the transmittance at the wavelength of interest. *Symbol:* **OD, $D(\lambda)$, D_{λ}**

NOTE 1—The higher the optical density, the lower the transmittance. Ten times the optical density is equal to the transmission loss expressed in decibels, e.g., an optical density of 0.3 corresponds to a transmission loss of 3 dB, i.e., 50 percent.

NOTE 2—Optical density can be expressed as

$$OD = \log_{10} \left[\frac{(E \text{ or } H)}{MPE} \right],$$

where E is the irradiance and H is the radiant exposure.

optical detector. A transducer that generates an output signal when irradiated with optical energy.

optical (fiber) connector. A device whose purpose is to transfer optical energy between two optical fibers or cables, or between a transmitter or a receiver and an optical fiber, and that is designed to be connected and disconnected repeatedly.

optical time domain reflectometer (OTDR). A device used for characterizing a fiber wherein optical pulses are transmitted through the fiber and the resulting light scattered back to the input is measured as a function of amplitude and time.

optical fiber. Any filament or fiber, made of dielectric materials, that guides light, whether or not it is used to transmit signals. *Syn:* **optical waveguide, lightguide.**

optical fiber communications system (OFCS). An engineered assembly for the generation, transference and reception of optical radiation arising from lasers or light-emitting diodes (LED), in which the transference is by means of optical fiber for communication purposes.

optically aided viewing. Intrabeam viewing with an optical device such as a handheld magnifier, e.g., eye-loupe, or a binocular or telescope. Telescopic optics generally increase the hazard to the eye by intrabeam viewing of a collimated beam when viewed at a distance. The increased risk arises from the ability of the optical aid to collect more energy than can enter the eye and be focused on the retina (wavelengths 0.4 μm to 1.4 μm) or focused on the cornea (other wavelengths). Optically aided viewing does not include viewing with corrective eyewear or with indirect image converters.

point source. For purposes of this standard, a source with an angular subtense at the cornea equal to or less than alpha min ($\alpha_{\min}$), i.e., $\alpha \leq 1.5 \text{ mrad}$.

point source viewing. The viewing condition whereby the eye is located within the beam or the angular subtense of the source, α , is equal to or less than the limiting angular subtense, $\alpha_{\min}$.

primary beam (FSOCS). The beam that transmits the modulated data signal.

pulse duration. The duration of a laser pulse, usually measured as the time interval between the half-power points on the leading and trailing edges of the pulse. Typical units: millisecond (ms) = 10^{-3} s; microsecond (μs) = 10^{-6} s; nanosecond (ns) = 10^{-9} s; picosecond (ps) = 10^{-12} s; femtosecond (fs) = 10^{-15} s.

pulse-repetition frequency (PRF). The number of pulses occurring per second, expressed in hertz. *Symbol:* ***F***

radiance. Radiant flux or power output per unit solid angle per unit area expressed in watts-per-centimeter squared per steradian ($\text{W}\cdot\text{cm}^{-2}\cdot\text{sr}^{-1}$). *Symbol:* ***L***

radiant exposure. Surface density of the radiant energy received, expressed in units of joules per-centimeter squared ($\text{J}\cdot\text{cm}^{-2}$). *Symbol:* ***H***

NOTE—The terms *energy density* and *fluence* are sometimes used as synonyms for *radiant exposure*, although these terms have slightly different technical meanings.

radiant intensity. Quotient of the radiant flux leaving a source and propagated into an element of solid angle containing the direction, by the element of solid angle. The SI unit of radiant intensity is watts per steradian ($\text{W}\cdot\text{sr}^{-1}$). *Symbol:* ***I***

radiant power. Power emitted, transferred or received in the form of radiation. The SI unit of power is watts (W). *Symbol:* **Φ** *Syn:* **radiant flux.**

reasonably foreseeable event. For purposes of this standard, an event, incident or accident which is thought to be credible or plausible. This term can be expressed numerically, but the value will differ depending on the situation being assessed, and is not defined exactly in legislation due to the intrinsic subjectivity of its definition.

refraction. The bending of a beam of light in transmission through an interface between two dissimilar media or in a medium whose refractive index is a continuous function of position (graded index medium).

refractive index (of a medium). The ratio of the velocity of light in vacuum to the phase velocity in the medium. *Symbol: n Syn: index of refraction.*

repetitively pulsed laser. A laser with multiple pulses of radiant energy occurring in a sequence.

restricted location. *See: location types.*

retinal hazard region. Optical radiation with wavelengths between 0.4 μm and 1.4 μm , where the principal hazard is usually to the retina.

safety connectors. A connector which is designed to preclude, when removed, access to levels of radiant energy exceeding the appropriate MPE at any point in space.

secured enclosure. An enclosure to which casual access is impeded by an appropriate means, e.g., a door secured by a key lock or magnetically or electrically operated lock or latch, or by fasteners requiring a tool for removal.

service. The performance of procedures, typically defined as repair, to bring the OCS back to full and normal operational status. It does not include *installation*, *operation* or *maintenance* as defined in this section.

service organization. An organization or individual responsible for the service of an OCS.

single-mode optical fiber. An optical fiber (or optical waveguide) in which only the lowest-order bound mode or degenerate pairs of orthogonally polarized bound modes can propagate at the wavelength of interest.

step-index profile. A refractive index distribution in an optical fiber in which the core has a uniform refractive index and the cladding has a uniform lower refractive index.

special tool. For purposes of this standard, a tool intended for use with tamper-resistant fasteners that is not readily available at retail consumer hardware stores, e.g., a key.

solid angle. The three dimensional angular spread at the vertex of a cone measured by the area intercepted by the cone on a unit sphere whose center is the vertex of the cone. The SI unit of solid angle is steradian (sr).

spillover. The beam radiant energy that propagates past the receiving terminal in an FSOCS.

steradian. The unit of measure for a solid angle. There are 4π steradians about any point in space.

transmittance. The ratio of transmitted power (energy) to incident power (energy).

unaided viewing; viewing without optical aids. Visual observation without magnification, as with the naked eye (prescription eyeglasses and contact lenses are not considered optical aids).

unrestricted location. *See: location types.*

3. Hazard Evaluation

3.1 General

The following principal aspects of an OCS influence the total hazard evaluation and, thereby, influence the application of control measures:

- a) The capability of the radiant energy to injure people, which is determined by the hazard classification for normal operation and the hazard level (OFCS) and access level (FSOCS) during installation, maintenance and service.
- b) The location type in which the OCS is used.
- c) The persons potentially exposed and their level of activity, training (if any) and awareness.

The total hazard evaluation procedure shall consider all three aspects along the entire beam path using the concepts of access levels for FSOC and hazard levels for OFCS (see 1.3).

3.2 Hazard Classification

Normally, the hazard classification of a laser product is provided by the manufacturer. The classification is based upon intended operation, and for that reason, an OFCS is normally Class 1 since the radiant power remains totally confined in the fiber. For OCS that have not been certified by the manufacturer in accordance with the FLPPS or IEC 60825-1, the individual responsible for determining the hazard level or access level shall ensure that the optical fiber characteristics, including data sufficient for determining the divergence of a fiber (OFCS), and the optical output data, including data sufficient for determining the beam divergence and NHZ (FSOCS), are valid. For laser equipment certified according to the FLPPS or IEC 60825-1, the manufacturer will include all optical parameters in its user documentation. The LSO or responsible individual should consult the user manual and/or manufacturer for correct optical fiber characteristics. Hazard classification shall be based on the maximum output power available taking into account the APR or IPS, if included in the system.

3.2.1 Laser Hazard Classes

3.2.1.1 Class 1 and Class 1M Lasers and Laser Systems. Any laser, or laser system that cannot emit accessible laser radiation levels in excess of the applicable Class 1 AEL for any emission duration within the maximum duration inherent in the design or intended use of the laser or laser system is a Class 1 laser or laser system during operation. The maximum exposure duration is assumed to be no more than 30,000 s, except for infrared systems not intended to be viewed ($\lambda > 0.7 \mu\text{m}$) where 100 s shall be used.

Lasers or laser systems intended for a specific use may be designated Class 1 by the LSO on the basis of a limiting exposure duration of T_{max} less than 100 s, provided that the accessible laser radiation does not exceed the corresponding Class 1 AEL for any emission duration within the maximum duration inherent in that specific use.

Any laser, or laser system that cannot emit accessible laser radiation levels in excess of the Class 1 AEL (Table 1) under MPE measurement criteria in Table 4c, but exceeds the Class 1 AELs under Condition 1 or Condition 2, or both (Table 4c), but does not exceed the Class 3B AEL for any emission duration within the maximum duration inherent in the design or intended use of the laser or laser system is a Class 1M laser or laser system.

3.2.1.1.1 Class 1 and Class 1M AELs. To determine the laser's potential for injury, it is necessary to consider not only whether the laser output irradiance or radiant exposure exceeds the MPE for the unaided eye, but also whether a hazard would exist if the laser beam power or pulse energy were concentrated by optics and confined to the area of the limiting aperture for the applicable MPE for the eye (Tables 5a and 5c). Tables 4a, 4b and 4c provide the measurement apertures for the measurement of the AEL (energy or power). The AEL for Class 1 is the identical energy for Class 1M, but the measurement conditions differ.

The Class 1 AEL is defined in two different ways, depending on whether the laser is considered a "point" source or an extended source (an unusual case).

Point sources: Most lasers can be considered point sources (see 8.1 for criteria). For such lasers, the Class 1 AELs shall be determined by the product of two factors:

- a) The MPE for the unaided eye (Table 5a) for the limiting exposure duration $T_{\max}$
- b) The area of the limiting aperture for the eye from Table 4a, i.e., the Class 1 AEL = MPE $\times$ (area of the limiting aperture)

Extended sources: For lasers or laser systems that are extended sources, e.g., a ribbon or cable comprised of a number of optical fibers, and emit in the spectral range 0.6 μm to 1.4 μm , the MPE to be used in calculating the Class 1 AELs shall be determined from Table 5b. For thermal effects, the MPEs for extended sources are greater (less stringent) than the point source MPEs listed in Table 5a, the degree of increase is dependent upon a correction factor C_E and the exposure duration t . The value of C_E is subject to the following conditions:

- a) When telescopes will not be used, C_E is computed for the angle subtended by the source when viewed at the minimum accessible viewing distance or 10 cm, whichever is greater, and for Condition 2 of Table 4c, at 10 cm, and,
- b) C_E is computed for the angle subtended by the source at the entrance aperture of an ordinary 7-power optical viewing system (50-mm limiting entrance aperture, 7 mm exit aperture) multiplied by the magnification of the optics ($M = 7$). The subtended angle for optically-aided viewing is computed at the minimum accessible viewing distance or 2 m, whichever is greater.

Photochemical effects can occur at wavelengths shorter than 0.6 μm . Because almost all OCS emitters operate at longer wavelengths, wavelengths shorter than 0.6 μm are not directly addressed in this document. (Refer to ANSI Z136.1 for the applicable MPE and AEL values, which are based on radiance and integrated radiance averaged over a cone angle γ .)

NOTE—For typical optics, a maximum transmission that would be expected is 90% in the wavelength range 0.4 μm to 0.7 μm , and 70% in the wavelength range of 0.7 μm to 2.8 μm .

If this determination is difficult to apply, point source MPEs from Table 5a may be used and will result in a conservative Class 1 AEL.

3.2.1.2 Class 2 and 2M Visible Lasers and Laser Systems. Class 2 and 2M lasers are visible ($0.4\ \mu\text{m}$ to $0.7\ \mu\text{m}$) CW and repetitive-pulse lasers and laser systems that can emit accessible radiant energy exceeding the appropriate Class 1 AEL for the maximum duration inherent in the design or intended use of the laser or laser system, but cannot exceed the Class 1 AEL for any applicable pulse (emission) duration $T < 0.25\ \text{s}$ and cannot exceed an average radiant power of 1 mW. Class 2M lasers and laser systems pose the same ocular hazards to the unaided eye as Class 2, but are potentially hazardous when viewed with optical aids.

3.2.1.2.1 Class 2 and Class 2M AELs. The Class 2 and 2M AELs shall be determined in the same manner as Class 1 AELs, except the MPE values are based on an exposure duration of 0.25 s (aversion response). For CW point source conditions, the MPE is $2.6\ \text{mW cm}^{-2}$ and the AEL is 1 mW.

3.2.1.3 Class 3 Lasers and Laser Systems

3.2.1.3.1 Class 3R Lasers and Laser Systems. Class 3R lasers and laser systems include lasers and laser systems that have an accessible output between 1 and 5 times the Class 1 AEL for wavelengths shorter than $0.4\ \mu\text{m}$ or longer than $0.7\ \mu\text{m}$, or less than 5 times the Class 2 AEL for wavelengths between $0.4\ \mu\text{m}$ and $0.7\ \mu\text{m}$.

3.2.1.3.2 Class 3B Lasers and Laser Systems. Class 3B lasers and laser systems include:

- a) Infrared lasers and laser systems that can emit radiation between $1.4\ \mu\text{m}$ and $1\ \text{mm}$ at an accessible radiant power in excess of the Class 3R AEL during any emission duration within the maximum duration inherent in the design of the laser or laser system, but which (a) cannot emit an average radiant power in excess of 0.5 W for $t \geq 0.25\ \text{s}$ or (b) cannot produce a radiant energy greater than 0.125 J for $t < 0.25\ \text{s}$.
- b) Visible ($0.4\ \mu\text{m}$ to $0.7\ \mu\text{m}$) or near-infrared ($0.7\ \mu\text{m}$ to $1.4\ \mu\text{m}$) lasers or laser systems that emit in excess of the AEL of Class 3R but (a) cannot emit an average radiant power in excess of 0.5 W for $t \geq 0.25\ \text{s}$ and (b) cannot produce a radiant energy greater than $0.03\ C_A\ \text{J}$ per pulse. Pulses separated by less than $t_{\min}$ are considered a single pulse.

3.2.1.4 Class 4 Lasers and Laser Systems. Class 4 lasers and laser systems are those that emit radiation that exceed the Class 3B AEL.

3.2.2 General Considerations for Classification

3.2.2.1 Radiometric Parameters for Classification. Classification of essentially all lasers requires the following radiometric parameters:

- a) Wavelength(s) or wavelength range.
- b) For CW or repetitive-pulse lasers: average power output within specified limiting apertures (effective power) and limiting exposure duration $T_{\max}$ inherent in the design or intended use of the laser or laser system.
- c) For pulsed lasers: total energy per pulse (or peak power per pulse) within specified limiting apertures (effective energy), pulse duration, pulse repetition frequency and emergent beam radiant exposure.

NOTE—The evaluation of an OFCS with pulse-repetition frequencies (PRFs) less than 55 kHz at wavelengths less than $1.05\ \mu\text{m}$, and PRFs less than 22 kHz at wavelengths between $1.05\ \mu\text{m}$ and $1.4\ \mu\text{m}$, requires the determination of the number of pulses occurring

within one exposure duration and the MPE per pulse. Such conditions would be very rare for any OCS, where the duty cycle is normally of the order of 0.5 and the baud rates are far higher (see Section 8). Otherwise, MPE values for continuous wave (CW) OCS apply (see 8.2).

- d) Angular subtense of the source (α). Most OCS sources are either not an extended source, or the angular subtense of the source α is sufficiently small that the source can be treated as a point source, and this parameter can be ignored. (See 3.2.2.3 for those cases where α should not be ignored.)

3.2.2.2 Multi-wavelength OCS. The classification of OCS capable of emitting multiple wavelengths shall be based on the most hazardous possible operation. For systems where more than one wavelength is used, such as a wavelength division multiplex system (WDM), the hazard level depends on both the power levels and whether the hazard level at each wavelength is additive. For skin exposure at wavelengths usually used in OCS, the hazard levels are always additive. For most OCS, 1.4 μm is the point at which the additive conditions change:

- a) If two wavelengths are both below 1.4 μm (retinal hazard region), they are additive, i.e., the combined hazard is higher.
- b) If two wavelengths are both above 1.4 μm , they are additive, i.e., the combined hazard is higher.
- c) If one wavelength is above 1.4 μm and one is below, the hazards are not additive, i.e., the combined hazard does not increase.

It is necessary to calculate separately for skin and retinal hazards. For multi-wavelength systems within a wavelength region, it is necessary to calculate the combined hazard level of the system at each wavelength as a proportion of the AEL for that hazard level and add the results.

3.2.2.3 Extended Source Lasers or Laser Systems. Classification of extended-source lasers or laser systems (such as laser arrays, optical fiber cables, injection laser diodes, and lasers having a permanent diffuser within the output optics) requires, in addition to the parameters listed in 3.2.2.1, knowledge of the apparent visual angle subtended by the source, e.g., spacing between optical fibers in a ribbon or cable.

3.2.2.4 Use of APR and IPS to Determine Hazard Class. APR and IPS may be used in order to classify an OCS, or a portion of the system, at a lower class than the laser/LED power of that system would otherwise permit. This is important when the class of the internal optical transmitters of a system may put a limitation on where that system may be deployed. (See 3.4.2.4 and 3.5.2.)

3.2.2.5 Measurement Distance. Classification of highly diverging beam lasers, e.g., OFCS, the emission from the end of an unterminated optical fiber, requires determination of effective power or energy transmitted through a specified limiting aperture at a specified distance (see Section 9 and Table 4b and Table 4c).

Classification of expanded, collimated beam laser products, e.g., FSOCS, requires the determination of hazards from optically aided viewing, i.e., telescopes and binoculars. Measurements are made at the closest viewing distance, but no closer than 2 m, for all wavelengths that transmit through common optics. When determining classification, the correct

measurement aperture (see Table 4b and Table 4c) and optics transmission values (see 3.2.1.1.1) should be chosen. For determining potential hazards from unaided viewing at a distance, the apertures given in Table 4a are used for a measurement at the location of interest.

3.2.2.6 Labeling for Classification. Products classified above Class 1 in accordance with the FLPPS or IEC 60825-1 will have a label indicating the classification of the system in normal operation.

3.3 General Considerations

3.3.1 Environment. The environment is one of the factors that determine the nature of control measures. These differ for OFCS and FSOCS as noted in 3.4 and 3.5.

3.3.2 Nominal Hazard Zones. Where applicable, e.g., in the presence of unenclosed Class 3B and Class 4 beam paths, the LSO shall be responsible for establishing the NHZ. If the beam of an unenclosed Class 3B or Class 4 laser or laser system is contained within a region by adequate control measures to protect people from exposure above the appropriate MPE, that region may be considered to contain the NHZ. The NHZ may be determined from information supplied by the laser or laser system manufacturer, by measurement, or by using the appropriate laser range equation or other equivalent assessment as described in this section and Appendix B.

The LSO shall ensure that consideration is given to direct, reflected and scattered radiation in the establishment of boundaries for the laser controlled area. Control measures are only required within the NHZ (see Section 4). Viewing the main beam or a specular-reflecting laser target with an optical instrument is potentially hazardous due to the instrument's light-gathering capability (see B.3.2.6.3 in Appendix B). Therefore, use of such optical systems may effectively increase the NHZ boundaries and must be considered in the overall hazard analysis.

3.3.3 Personnel. Personnel who may be in the vicinity of a laser and its emitted beam(s), including maintenance personnel, service personnel and the operator, can influence the total hazard evaluation and, hence, influence the decision to adopt additional control measures. If children or others unable to read or understand warning labels may be exposed to potentially hazardous laser radiation, the evaluation of the hazard is affected and control measures may require appropriate modification. It must be kept in mind that for certain OFCS, the principal hazard control resides with the installation or operating organization, whose responsibility is to avoid aiming the laser at people or flat mirror-like surfaces during installation and service.

The following are considerations regarding operating personnel and those who may be exposed:

- a) Maturity of judgment of the laser user(s)
- b) General level of training and experience of the installation and service personnel
- c) Awareness on the part of onlookers that potentially hazardous laser radiation may be present and the relevant safety precautions
- d) Degree of training in laser safety of all individuals involved in the laser's operation
- e) Reliability of individuals to follow standard operating procedures (SOPs) and recommended control procedures

- f) Number of individuals and their location relative to the primary beam or reflections, and potential for accidental exposure
- g) Other hazards not due to laser radiation which may cause the individuals to react unexpectedly or which influence the choice of personnel protective equipment

3.4 Optical Fiber Communication Systems (OFCS)

3.4.1 Hazard Level. The seven hazard levels, Hazard Level 1, 1M, 2, 2M, 3R, 3B and 4, are defined in Section 2. The procedures in 1.3.1 for assigning the appropriate hazard level where and when the OFCS is being serviced or installed shall be used in the following instances:

- a) Where the hazard level/class and controls are not provided,
- b) Where the hazard level/class may change because of a change from the use intended by the manufacturer, or
- c) Where engineering controls are added or deleted (see Section 4).

Determination of the hazard level is the ultimate responsibility of the operating organization but may be determined by the maintenance, installation or service organization.

Table 8a offers a summary of the formulas for determining the AELs for the hazard levels for OFCS that operate at a pulse repetition frequency greater than 55 kHz for wavelengths less than 1.05 μm and greater than 22 kHz for wavelengths between 1.05 μm and 1.4 μm . Figures 5a through 8b show the corresponding values for typical optical fibers. Also, see Appendix B for examples of OFCS classification.

The OFCS hazard levels shall be determined according to its accessible emission level and specified wavelength(s) when operated at the maximum power for its intended use.

3.4.2 Stepwise Procedure for Evaluation. The recommended stepwise procedure for using this standard is as follows:

3.4.2.1 Determine the Appropriate Hazard Level/Class of Each Transmitter. Determine the appropriate classification of each transmitter in the system, i.e., of the complete operational network consisting of at least a transmitter, using the manufacturer's specifications for the product. If the laser-containing components of the system have been certified in accordance with the provisions of the FLPPS or IEC60825-1, information on wavelength, power output and beam divergence should be included in the manufacturer-supplied user manual. (In order to do this the output specifications of the components containing lasers or LEDs must be provided in radiometric units of watts, milliwatts, microwatts or dBm.) If this information is not available, the measurement methods described in Section 9 and the hazard evaluation and classification descriptions given in 3.2 should be used.

To use the MPE values in Section 8, first determine whether or not the MPE for an extended (large) source, as given in 8.1, should be used, e.g., if an LED is used. For the general case, i.e., point-source viewing, the MPE criteria in 8.2 shall be used. (See Figures A.1 and A.2 in Appendix A for illustrated viewing conditions and Figures A.3 and A.4 for the measurement arrangement used for hazard level classification.)

3.4.2.1.1 Radiometric Parameters Required for Determining the Hazard Level.

Determination of the appropriate hazard level for essentially all OFCS requires the following parameters:

- a) Wavelength(s) or wavelength range.
- b) For CW or repetitively pulsed OFCS: average power output; limiting exposure duration in a period of 100 s (for invisible wavelengths) inherent in the design or intended use of the OFCS and, depending on the optical fiber used, either the numerical aperture (NA) of a multimode fiber or the mode field diameter (ω_0) of a single-mode fiber. (The core diameter of a single-mode fiber may be used if ω_0 is not provided.) When lens connectors are used, the beam diameter and beam divergence associated with the connector must be known. (Table 8a contains the formulas for determining the maximum optical power that corresponds to the hazard levels for multi-mode and single-mode optical fibers; Figures 5 through 7 show the AELs for commonly used wavelengths and selected fiber parameters.)
- c) If APR is used to control the hazard level, the shutdown time and restart pulse duration and frequency.

NOTE—Laser equipment certified in accordance with the FLPPS, FDA/CDRH Laser Notice No. 507, or IEC 60825-1 requires the manufacturer to include this information in the documentation supplied with the equipment.

Hazard level determination of an extended-source OFCS, e.g., a cable comprised of a linear array (ribbon) or a two dimensional array of optical fibers, requires that, in addition to the parameters listed above, the maximum viewing angular subtense (apparent visual angle) and, hence, the fiber spacing and dimensions of the array, must also be known if relying on these mitigation elements to relax MPE values or reduce hazard levels (see 8.1).

3.4.2.2 Evaluate the Location Type. The following three location types are used with OFCS:

- a) *Unrestricted access*: A location where access to the beam path is unrestricted. Examples include domestic premises and premises open to the public.
- b) *Restricted access*: A location where access to the protective housing (enclosure) is not accessible to the public. Examples include secured areas within industrial areas not open to the public and overhead cables and cables drops to a building.
- c) *Controlled access*: A location where access to the enclosure (protective housing) is controlled and is accessible only to authorized persons who have received adequate training in laser safety and servicing of the system. Examples include optical cable in cable ducts, buried cables and dedicated areas of network operator distribution facilities.

The type of location will determine the degree of controls required for each of the hazard levels.

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3.4.2.3 Comply with the Applicable Control Measures. Comply with the specified control measures for the appropriate hazard level using Table 3.2 as a guide.

3.4.2.4 Use of APR to Determine the Hazard Level. APR may be used in order to classify an OFCS or portion of an OFCS at a lower hazard level than the laser/LED power of that system would otherwise permit. This is important when the hazard level of the internal optical transmitters of a system may put a limitation on where that system may be deployed.

The assessment of the hazard level, when APR is used, shall take place:

- a) 1 second after the fiber break or disconnect, unless measurement at a later time would result in a larger exposure, or
- b) 3 seconds after the fiber break or disconnect for restricted and controlled locations, unless measurement at a later time would result in a larger exposure.

Additionally, for locations with a hazard level lower than that which would be assigned if APR were not employed, the irradiance or radiant exposure during the maximum time to reach the lower hazard level specified in the preceding paragraph shall not exceed the irradiance or radiant exposure limits (MPE) for the corresponding conditions shown in Table 3.1.

Table 3.1 – Maximum Time to Reach Lower Hazard Level when APR is Used

Location Type	Maximum time to reach lower hazard level (seconds)	Distance from aperture to fiber (mm)
Unrestricted	1	100
Restricted	3	100
Controlled	3	250

Table 3.2 – OFCS Requirements

Hazard Level	Location Type		
	Unrestricted	Restricted	Controlled
1	No requirements	No requirements	No requirements
2 and 2M	Labeling <u>and</u> Class 1 from connector ^a or connector requires tool	Labeling Training	Labeling Training
1M and 3R	Labeling <u>and</u> Class 1 from connector ^a or connector requires tool	Labeling Training	Labeling Training
3B	Not permitted ^b	Not permitted ^b	Labeling Protected cable and 1M or 2M from connector ^a or connector requires tool. Training
4	Not permitted ^b	Not permitted ^b	Not permitted ^b

^a To be achieved by mechanical design of connector, automatic power reduction or other suitable means.

^b Where systems employ power levels of Class 1M/2M/3R or more, protection systems such as APR may be used to obtain the acceptable hazard level for the particular location type.

Restart of such systems shall not take place for another 100 seconds minus the reduction time in seconds, unless the continuity of the link can be assured.

NOTE—Faster shutdown times may be required to meet the MPE values during power reduction.

3.5 Free-space Optical Communication Systems (FSOCS)

3.5.1 General. The total hazard evaluation of a particular FSOCS depends on defining the extent of several potentially hazardous conditions. In this evaluation, consider all optics (lenses, mirrors, fiber optics, etc.) that are a permanent part of the laser beam path. This may be done in a step-by-step manner as described in the following 6 steps: