

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

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

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 $\alpha_{\min}$.

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 (α_{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, α_{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.

⁷ Laser Notice No. 50—Laser Products - Conformance with IEC 60825-1 and IEC 60601-2-22.

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:

- a) Determine the NHZ of the laser. Calculations of radiant exposure or beam irradiance as a function of range can be made with the range equation for a circular beam (see B.3.2.6.2 in Appendix B). Consider the potential use of telescopes and binoculars.
- b) Evaluate potential hazards from transmission through windows and specular reflections. Specular surfaces ordinarily encountered (for example, windows and mirrors in vehicles and windows in buildings) are oriented vertically and will usually reflect a horizontal beam in a horizontal plane.

As much as 8% of the beam's original irradiance or radiant exposure can be reflected toward the laser from a clear glass window that is oriented perpendicular to the beam. If the beam strikes a flat, specular surface at an angle, a much greater percentage of the beam can be reflected beyond, or to the side of, the target area. Specular reflective surfaces, such as raindrops, wet leaves and most other shiny natural objects, seldom reflect hazardous radiant intensities beyond a meter from these reflectors.

- c) Determine whether hazardous specular reflections exist (see B.3.2.6.1 in Appendix B). Determine the corresponding NHZ.
- d) Evaluate the stability of the laser platform (including the effects of wind and other environmental conditions for outdoor use) to determine the extent of lateral range control and the lateral constraints that should be placed on the beam traverse. Determine the corresponding NHZ during operation.
- e) Consider the likelihood of people being in the NHZ.
- f) Consider the likelihood and effects of spillover.

3.5.2 Access Levels. The seven access levels are Access Level 1, 1M, 2, 2M, 3R 3B and 4 are defined in Section 2. The procedures in 1.3.1 for assigning the appropriate nominal hazard zones (NHZ) and access level where and when the FSOCS is being serviced or installed shall be used in the following instances:

- a) Where the laser or laser system access level/class and controls are not provided,
- b) Where the access 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 access levels is the ultimate responsibility of the operating organization. However, they may be determined by the maintenance, installation or service organization. The methods for determining compliance with an access level are the same as those described for classification in ANSI Z136.1 except for the following:

- a) The access level within a designated location shall be determined at any position relative to an FSOCS transmitter where the access level is maximized, and could depend on intermediate system elements such as windows.
- b) The access level may depend on the activation of an IPS or APR system.
- c) If an IPS is monitoring the location in question, the accessible emission shall not exceed the MPE during the 2 seconds immediately following any human interception of the

beam. Otherwise, the same method used for classification is also used for determination of access level. For viewing conditions without optical aids refer to Table 1.

NOTE—Rationale for 2 seconds: Because of the difficulty of a person with binoculars or other optical aid to fully align with the beam, it is unlikely that a person could intercept the beam's full power within 2 seconds. During the 2-second period following interception, no part of the body would be exposed above the optically unaided MPE for access levels of 1, 2, 1M or 2M. For an access level of 3R, the maximum exposure during the 2-second period following exposure is the Class 3R AEL without optical aids.

3.5.2.1 Radiometric Parameters Required for Determining the Access Level.

Determination of the appropriate access level for essentially all FSOCS requires the following parameters:

- a) Wavelength(s) or wavelength range
- b) For CW or repetitively pulsed FSOCS, average power output and limiting exposure duration in a period of 100 s (for invisible wavelengths) inherent in the design or intended use of the FSOCS
- c) If IPS is used to control the access level, the shutdown time and restart pulse duration and frequency

NOTE—Laser equipment certified according to the FLPPS, CDRH Laser Notice No. 50 or IEC 60825-1 requires the manufacturer to include this information in the documentation supplied with the equipment.

3.5.2.2 Location Types. The four location types for FSOCS are:

- 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 beam at levels exceeding the Class 1 AELs is not accessible to the public. Examples include transmitters in secured areas within buildings and on rooftops that are not open to the public.
- c) *Controlled access*: A location where access to the 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.
- d) *Inaccessible access*: A location where access to the beam at levels exceeding the Class 1 AELs is normally not accessible, e.g., 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.

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

3.5.3.1 Determine the Appropriate Hazard Classification of Each Transmitter. Determine the appropriate classification of each transmitter in the system using the manufacturer's specifications for the product and the corresponding access level. 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. (In order to do this the output specifications

of the components containing lasers 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.

For quantitative evaluation of the potential hazard associated with a given FSOCS, Sections 8 and 9 should be consulted. 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. 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 Figure A.3 for the measurement arrangement used for access level classification.)

3.5.3.2 Evaluate the Location Type. The type of location will determine the degree of controls required for each of the access levels. The four location types: unrestricted access, restricted access, controlled access and inaccessible access, are defined in Section 2.

3.5.3.3 Comply with the Appropriate Control Measures. Comply with the control measures specified for the appropriate hazard level using Table 3.3 as a guide.

Table 3.3 – Restrictions for Equipment Classes and Access Levels

Location type	Permissible equipment classes and installation conditions	Permissible Access Level
Unrestricted	Class 1 or 2 – No conditions Class 1M or 2M – See 4.4.2.1.1 Class 3R – See 4.4.2.1.2	1 or 2
Restricted	Class 1, 2, 1M or 2M – No conditions Class 3R – See 4.4.2.2.1	1, 2, 1M or 2M
Controlled	Class 1, 2, 1M, 2M or 3R – No conditions Class 3B or 4 – See 4.4.2.3.1	1, 2, 1M, 2M or 3R 3B or 4 – See 4.4.2.3.1
Inaccessible space	Not applicable	1, 2, 1M, 2M or 3R
NOTE—Examples of typical lasers classified in accordance with this standard are given in Appendix A; examples of calculations which may be useful in applying this standard are given in Appendix B.		

3.5.4 Examples. In each site where optical energy is transmitted, crossing into or received, respective exposure conditions shall be individually evaluated. Furthermore, the access level of potentially occupied locations along the beam path, within the NHZ or ENHZ, shall be evaluated and this will determine the appropriate controls to be applied (Table 3.3). Locations traversed by partial reflections from windows within the beam path shall also be evaluated if the emission could exceed Access Level 1 or 2. Both the transmitted and the received optical radiation shall be determined at a given site; the higher value shall be used to determine the access level and the appropriate control measures.

Example: In the case of a site that receives Access Level 1 or 2 radiation but uses a Class 1M transmitter in the opposite direction, these combined conditions are acceptable for restricted locations but not for an unrestricted location unless the transmission equipment is installed in a manner to reduce the transmit Access Level to 1 or 2.

Example: For links with spillover beyond the receiver, but within the ENHZ that is of Access Level 1M or 2M, the spillover (and any accessible radiation otherwise outside of the receiver path, e.g., in front of it) must be contained within a restricted or controlled location, an unrestricted location compliant with 4.4.2.1.2 or inaccessible space.

For Class 3B and 4 transmitters in controlled locations, the entire beam path that potentially passes through other location types, including inaccessible space, shall comply with the access level restrictions of Table 3.3. This may be satisfied in some applications by continually monitoring the entire NHZ to ensure rapid automatic power reduction in the event of human interception of the beam path. Any spillover beyond the receiver, and any accessible radiation otherwise outside of the receiver path within the NHZ, shall also be contained in a controlled location or inaccessible space. Any additional spillover within the ENHZ shall be contained within a restricted or controlled location, an unrestricted location compliant with 4.4.2.1.2 or inaccessible space.

The following ranking of the access levels (in increasing order of hazard) shall apply in this standard: Access Level 1, 2, 1M, 2M, 3R, 3B, 4.

NOTE—Because of the application, this ranking may not be the same as the ranking used in other standards.

4. Control Measures

4.1 General Considerations (OCS)

It must be recognized that the hazard evaluation relates specifically to the OCS product and its potential hazard based on operating characteristics. However, the location types, the level of safety training of individuals servicing the system, and other environmental and personnel factors are important considerations in determining the extent of safety control measures required. Because such situations require informed judgments by responsible persons, major responsibility for such judgments should be delegated to a qualified person, e.g., an LSO.

When hazard level 1M, 2, 2M, 3R, 3B or 4 systems are serviced, management (employer) is responsible for the establishment and surveillance of the appropriate control measures. The person responsible for laser safety shall ensure that the required safety information for the components of the OCS is available for determining the hazard level and the appropriate controls for the system. Engineering controls, which are incorporated into the OCS or that have been added by the user, shall not be eliminated (notwithstanding their use not being required by this standard). Priority should be given to the use of engineering controls, e.g., APR, as an integral part of OCS to control applicable potential hazards.

If the engineering controls of this section are impracticable or inadequate, personal protective equipment (PPE) and administrative and procedural controls should be used. Administrative and procedural controls are methods or instructions that specify rules or work practices, or both, which implement or supplement engineering controls and may specify the use of PPE. The limits of any type of control measure, e.g., failure modes of cables and connectors or the inability of some people to read hazard warnings, should always be considered in developing an OCS control program. When an LSO is not appointed, a qualified person, who is responsible for assuring that safe work practices are maintained should be designated by management. This person shall:

- a) Be trained in how to switch on and off the equipment
- b) Be conversant with laser safety instructions and requirements associated with the OCS equipment
- c) Display a responsible attitude towards laser safety
- d) Be named on a prominently displayed list of designated persons at each installation

If working on energized systems (live working) is not permitted, the designated person should be notified to verify that the OCS is de-energized before work on the equipment proceeds. (See Appendix C for guidance on safe work practices.)

NOTE—Unless otherwise specified, administrative and procedural controls apply only to Hazard Level 1M, 2, 2M, 3R, 3B OCS and Access Level 1M, 2, 2M, 3R, 3B FSOCS.

4.2 General Requirements for Installers of Turn-key (Ready-to-use) OCS

Installers of OCS transmitting equipment and/or turn-key end-to-end systems shall:

- a) Ensure that the equipment satisfies the product requirements of the FLPPS or IEC 60825-1, i.e., the alternative substitutions specified in Laser Notice No. 50, including:
 - 1. Product classification
 - 2. Engineering features, e.g., emission indicator, remote interlock connector
 - 3. Labels for that classification as well as manuals and other proper documentation
 - 4. Ensure that the equipment satisfies the product requirements of the FLPPS or IEC 60825-2, i.e., the alternative substitutions specified in Laser Notice No. 50, when an FSOCS incorporates optical fiber that extends out from the transmitting or receiving equipment.
- b) Provide the following additional information:
 - 1. Adequate description of any engineering design features incorporated into the product that prevent exposure to optical radiation in excess of Access/Hazard Level 1, 2, 1M, 2M or 3R.
 - 2. Adequate instructions for proper assembly, alignment, maintenance and safe use including clear warnings concerning precautions to avoid exposure to radiation above Access/Hazard Level 1, 2, 1M, 2M or 3R.

3. Adequate instructions for installation and service personnel to ensure the product can be installed and serviced in such manner that the accessible radiation does not exceed the requirements of 4.4. These include FSOCS requirements on horizontal and vertical spacing, definitions and requirements for unrestricted, restricted and controlled locations and inaccessible space, and, if allowed, the procedures and precautions applicable for any adjustments needed to increase/reduce beam divergence in order to reduce possible exposures.
 4. The reaction time and operating parameters of any APR system or IPS, if provided by the manufacturer; e.g., the time to reach the desired access or hazard level.
 5. Information specifying safe work practices and/or protection while power reduction systems or monitors (APR, IPS) are overridden, and safe procedures for reinstating and testing such systems.
 6. Sufficient information from the equipment manufacturer to allow the determination of the maximum access level at any position relative to the transmitter.
 7. Instructions for connection of an IPS to the remote interlock connector or equivalent transmitter interface.
 8. Appropriate information for FSOCS locations that do not employ transmitters on whether the receiver requires reception of optical emissions in excess of the MPE with optical aids and how to deploy that receiver properly.
 9. Warning and explanatory labels for Class 1M FSOCS transmitters that are visible during operation, i.e., not optional as stated in IEC 60825-1.
 10. Any other information relevant to the safe use of the OCS product.
- c) Except for Class 1, Class 1M, Class 2 or Class 2M OCS:
1. Provide adequate laser safety training to installation and service personnel.
 2. Ensure that suitable access controls and area warning signs are employed per Table 4.1. Each FSOCS location requiring a sign shall contain the words "Access Level xx, IEC 60825-12 (2004)." Area warning signs are to be posted adjacent to the equipment and next to entrance doors.
 3. Ensure APR systems and IPS monitors, if used, are providing the protection intended.
 4. For Class 3B and 4 FSOCS, verify by analysis or test that the access levels of received radiation in unrestricted and restricted locations and received or transmitted radiation in controlled locations are met under reasonably foreseeable conditions including consideration of beam alignment stability and mounting limitations.

4.3 OFCS

4.3.1 General Restrictions. The following restrictions apply for the installation of OFCS:

- a) OFCS or portions of OFCS of Hazard Levels 3R, 3B or 4 shall not be installed in unrestricted locations.

- b) OFCS or portions of OFCS of Hazard Levels 3B or 4 shall not be installed in restricted locations.
- c) OFCS or portions of OFCS of Hazard Level 4 shall not be installed in controlled locations.

4.3.2 Engineering Controls

4.3.2.1 Cable Connectors.

- a) *Unrestricted locations:* All systems operating in unrestricted locations in which cable connectors are accessible require the use of a tool for access or disconnection if Hazard Level 1 can be exceeded.
- b) *Controlled locations:* All systems operating in controlled locations in which cable connectors are accessible require the use of a tool for access or disconnection if Hazard Levels 1M/2M/3R are exceeded.

The positioning of the connector in a way that prevents human access to a higher Hazard Level is an acceptable feature to ensure that these requirements are met. The incorporation of an APR system may be used to reduce the hazard level to one appropriate for the location (see 3.2.2.4).

4.3.2.2 Labeling. Labeling, in the form of sleeves, tags or tape, shall be used in a manner that is easily associated with each connector where the hazard level is in excess of Hazard Level 1.

For the OFCS, or portion of the OFCS where the hazard level is known and cannot be changed to a higher hazard level anywhere within the OFCS, and where safety connectors are not used, labels which include the following wording shall be used:

- a) For Hazard Level 2

CAUTION – DISCONNECTED OPTICAL CONNECTORS MAY EMIT OPTICAL RADIATION DO NOT STARE INTO BEAM
--

The words HAZARDOUS LIGHT may be used as in place of OPTICAL RADIATION.

- b) For Hazard Levels 1M, 2M and 3R

CAUTION – DISCONNECTED OPTICAL CONNECTORS MAY EMIT OPTICAL RADIATION DO NOT VIEW BEAM WITH OPTICAL INSTRUMENTS

c) For Hazard Level 3B

DANGER –
 DISCONNECTED OPTICAL CONNECTORS MAY EMIT
 OPTICAL RADIATION
 AVOID DIRECT EXPOSURE
 TO THE BEAM

NOTE 1—For all infrared Hazard Level 1M and 3R systems, i.e., wavelengths greater than 0.7 μm , the words INVISIBLE OPTICAL RADIATION should be used in place of OPTICAL RADIATION.

NOTE 2—Connectors which may emit optical energy at Hazard Level 3B shall have affixed the warning label in (c), unless a sign having the same wording is posted conspicuously nearby.

NOTE 3—A sign should be used in an area with a large number of connectors, e.g., an equipment bay or cable closet.

The labels shall be located in plain view on the equipment in the vicinity of the connectors, e.g., outlets, patch panels, patch cords.

4.3.3 Administrative Controls

4.3.3.1 Disconnected Fibers and Cable Breaks. If an optical fiber cable should become disconnected or accidentally break, the following practices should be followed:

- a) Do not examine, or look directly at, or stare into broken, severed or disconnected optical fibers or cables.
- b) De-energize the affected part of the OFCS if the means to do so is clear.
- c) Arrange for a trained service person to de-energize the OFCS and repair or replace the optical fiber or cable.
- d) Cover exposed end of optical fiber with a suitable cap or cover to block emission and protect the end of the fiber.

4.3.3.2 Installation and Service in Controlled Locations. Controlled locations are those whose occupancy is subject to control and supervision for the purpose of protection against optical hazards. Some OFCS installations or service conditions, e.g., splicing or removal of optical connectors, may result in accessible emission. Under these conditions the following administrative and procedural controls should be followed:

- a) Only authorized trained personnel shall be permitted to install or perform service on Hazard Level 1M, 2M, 3R or 3B OFCS portions of the OFCS.
- b) Working on energized systems should be avoided whenever possible. An appropriate procedure for de-energizing systems should be in place so that the system is not re-activated during maintenance and/or service procedures.

- c) Only authorized, trained personnel shall be permitted to use Hazard Level 1M, 2M or 3R OFCS test equipment during installation or service of OFCS containing Hazard Level 3B or 3R optical amplifiers.
 - d) All unauthorized personnel shall be excluded from the NHZ of Hazard Level 3B OFCS during installation and service when there is a possibility that these systems may become energized.
 - e) During installation or service, a broken optical fiber or unterminated connector should only be viewed with an indirect image converter or with a filtered optical instrument of optical density (OD) sufficient to reduce the exposure to levels below the appropriate MPE, unless it has been verified that all optical transmitters are turned off and will remain off during the installation or service operation.
 - f) During all splicing operations that require viewing the end of a fiber of a Hazard Level 1M, 2M, 3R or 3B, the laser or LED source on the fiber involved shall be de-energized or viewing systems incorporating personal protection shall be employed. A responsible person(s) shall verify that the system is de-energized before splicing proceeds. Where applicable, ensure compliance with the OSHA lockout/tagout requirements (29 CFR Part 1910.147).
 - g) The degree and level of education and training on safety concepts and procedures shall be in accordance with Section 5.
 - h) Eye protection devices that are specifically designed for protection against the optical energy from a Hazard Level 3B OFCS should be administratively required when engineering or other procedural administrative controls are inadequate to eliminate potential exposure in excess of the applicable MPE. Eye protection shall be worn during service or installation of Hazard Level 3B OFCS.
- NOTE—See 7.2 for recommendations for eyewear and other devices to protect the eyes against non-optical hazards, e.g., glass particles during fiber cleaving operations.
- i) During service or installation of a Hazard Level 3B OFCS where access panels or doors are removed or opened and the NHZ distance could exceed 100 cm (as may occur when lens connectors are used), means shall be used to contain the beam to preclude exposure of nearby people.

4.4 FSOCS

4.4.1 General Considerations. Product classification and access level restrictions by location type are summarized in Table 3.3 (Section 3). It must be recognized that the hazard level classification relates specifically to the FSOCS product and its potential hazard based on operating characteristics. However, the location types, the level of safety training of individuals servicing the system, and other environmental (access level) and personnel factors are important considerations in determining the extent of safety control measures. FSOCS containing Class 1M or higher lasers should only be installed by safety-qualified FSOCS installers. The safety-qualified FSOCS installer is an individual who is sufficiently trained to safely install the specific FSOCS. Because the use of Class 3B and 4 lasers, FSOCS require informed judgments by responsible persons. Major responsibility for such judgments should be delegated to a qualified person such as an LSO.

4.4.2 Access Level and Classification Requirements by Location Type. The location of the FSOCS shall determine the permissible access levels of emissions and the classification of equipment to be used and subsequent types of controls. Table 3.3 (Section 3) shows the acceptable equipment classes, and access levels for the different types of locations. Figures 4.1 and 4.2 of this section illustrate some of the physical constraints described in this section for commercial and residential areas.

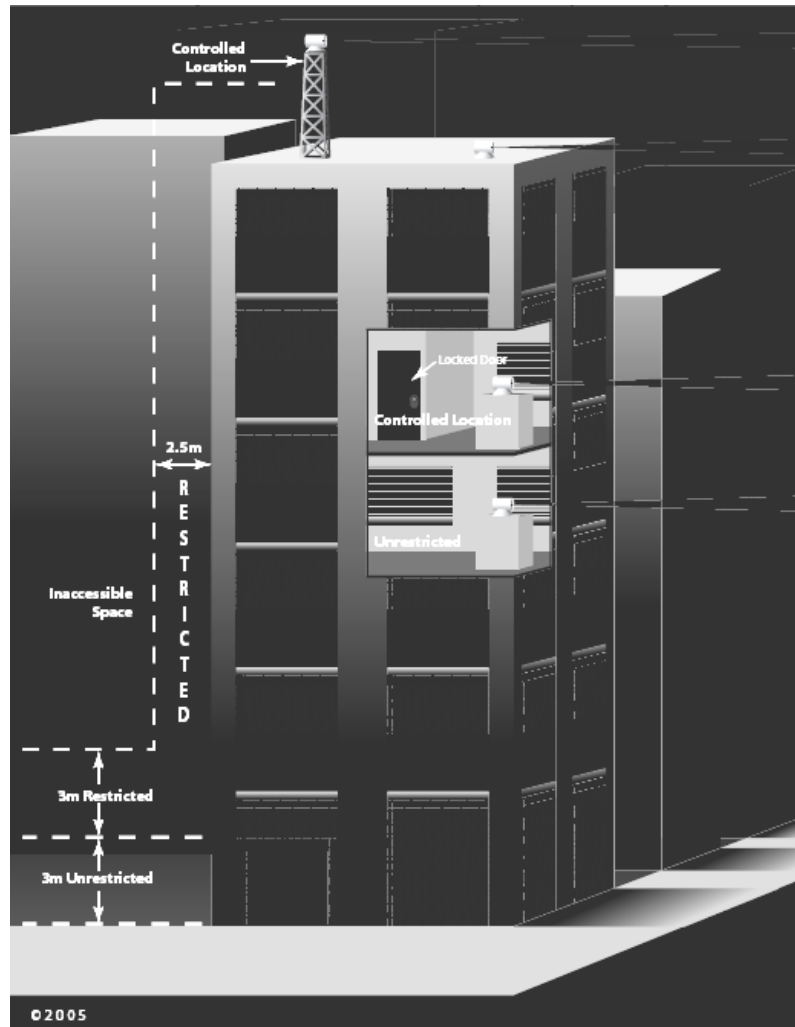


Figure 4.1 – Commercial Structures



Figure 4.2 – Residential Areas

4.4.2.1 Requirements for Unrestricted Locations. Unrestricted locations are those areas that are normally accessible to the public, e.g., unrestricted areas of rooftops, public areas at ground level, open areas of offices and industrial premises. For windows that can be opened or unenclosed balconies, the unrestricted region extends 1 meter horizontally from a perimeter boundary as shown in Figure 4.3.

The FSOCS emissions crossing into or received in an unrestricted location shall be Access Level 1 or 2. The open beam laser transmitters that are used in FSOCS and are installed without added conditions in unrestricted locations shall be Class 1 or Class 2.

4.4.2.1.1 Use of Class 1M and 2M Equipment in Unrestricted Locations. Installation and use of Class 1M or 2M transmitters in unrestricted locations is permitted if the following conditions are satisfied:

- a) The transmitter shall be installed and comply with at least one of the following:
 1. The use of optical aids within the extended NHZ is not a reasonably foreseeable event.

Collimated beam transmitters: For transmitters that do not satisfy Condition 1 of Table 4c, the installation shall not allow access to the ENHZ with binoculars or telescopes at distances greater than 2 meters from the transmitter. For example, locating Class 1M or 2M equipment near the edge of an unrestricted roof is permissible provided that all points within the ENHZ at distances greater than 2 meters from the transmitter are in a restricted location (beyond the 1-meter extension of the unrestricted location next to the roof edge as indicated in Figure 4.3). This condition is illustrated in Figure 4.5.

NOTE—It is not considered a reasonably foreseeable event to make use of binoculars or telescopes at distances closer than 2 meters from a transmitter. However, transmitters should be placed as close to a window or roof edge as reasonably possible.

Diverging beam transmitters: For transmitters that do not satisfy Condition 2 of Table 4c, the installation shall not allow access to the ENHZ with eye loupes or magnifiers at distances closer than 100 mm from the transmitter. For example, locating a Class 1M or 2M optical transmitter on a ceiling is permissible provided that a window or other barrier prevents access to points within the beam path closer than 100 mm from the transmitter.

NOTE—It is not considered a reasonably foreseeable event to make use of eye-loupes or magnifiers at distances closer than 100 mm from an FSOCS transmitter.

2. The transmitter shall provide an interlock connector that is interfaced with an IPS at the time of installation so that the accessible energy is limited to Access Level 1 or 2 as indicated in Figure 4.4.
- b) The installation shall ensure that there is no laser energy reflected back into the unrestricted location (from a window for example) that exceeds Access Level 1 or 2.
- c) The transmitter and/or shielding shall require a special tool to move/remove it, and a label that is visible to warn of the hazard before and after the transmitter or shielding is displaced. Alternatively, the transmitter and/or shielding shall be equipped with an interlock.

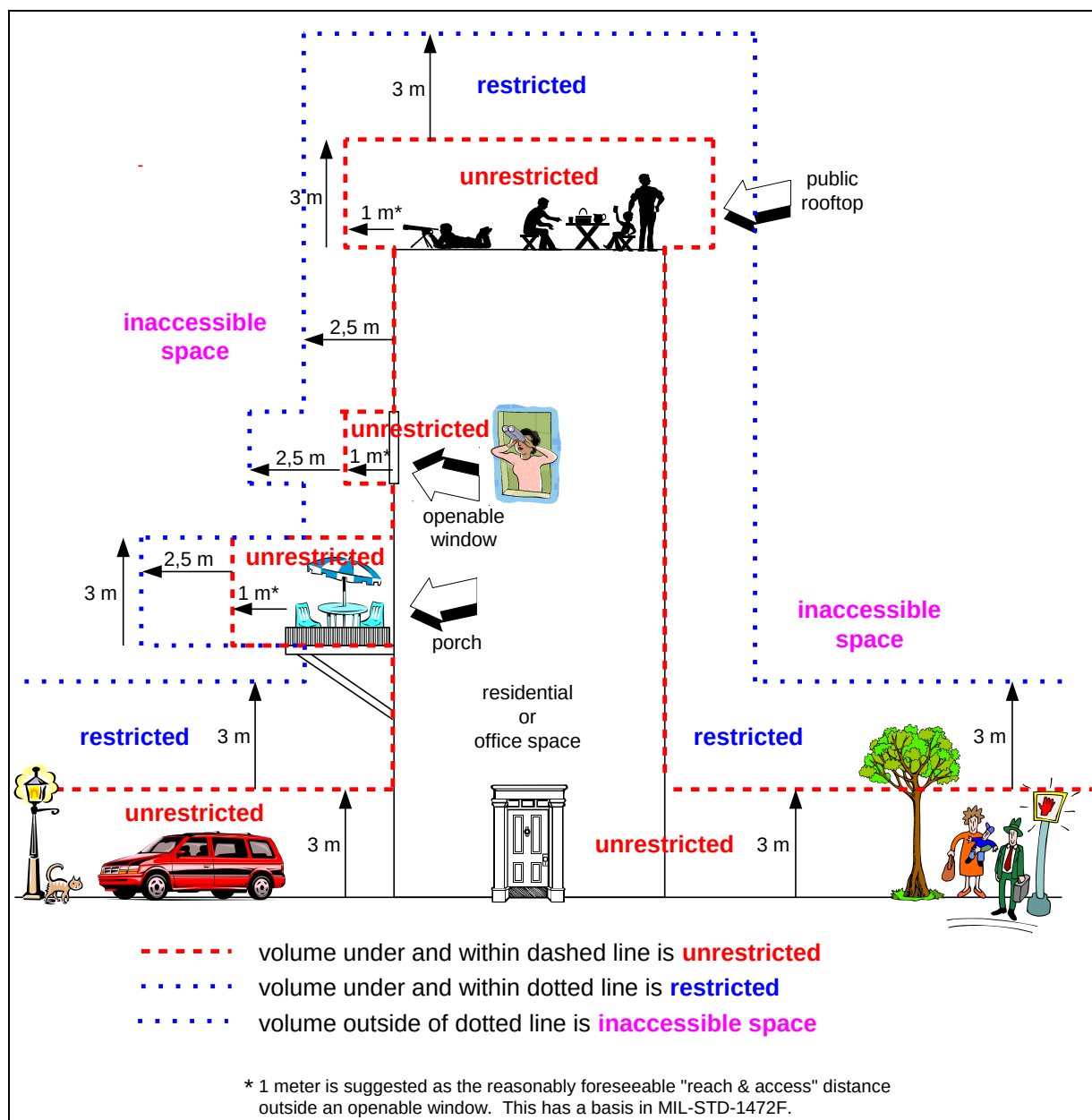


Figure 4.3 – Examples of External Location Types

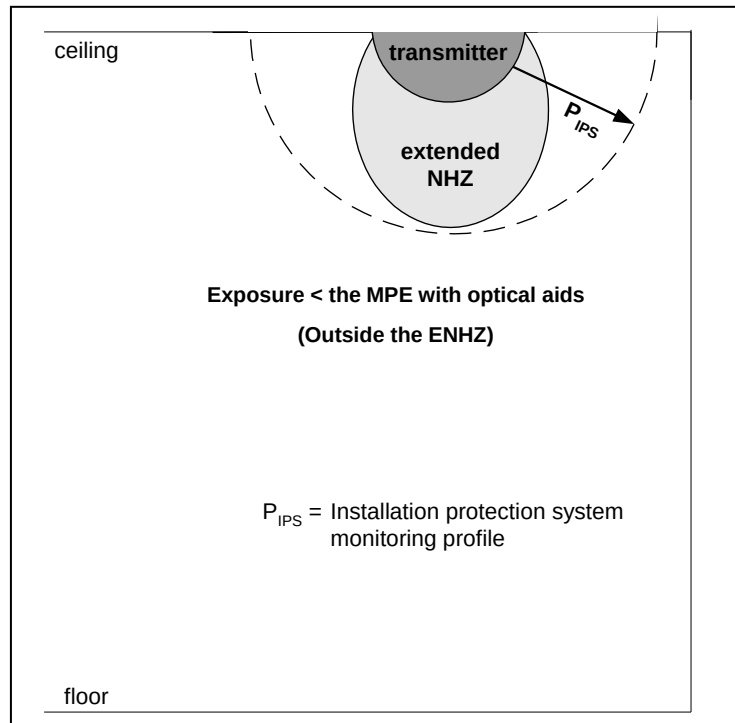


Figure 4.4 – Class 1M Transmitter in Unrestricted Location: An Example of an IPS that Monitors the Extended NHZ of a Class 1M Transmitter

NOTE—Power would be reduced to below the optically-aided viewing MPE if the monitored volume has been violated.

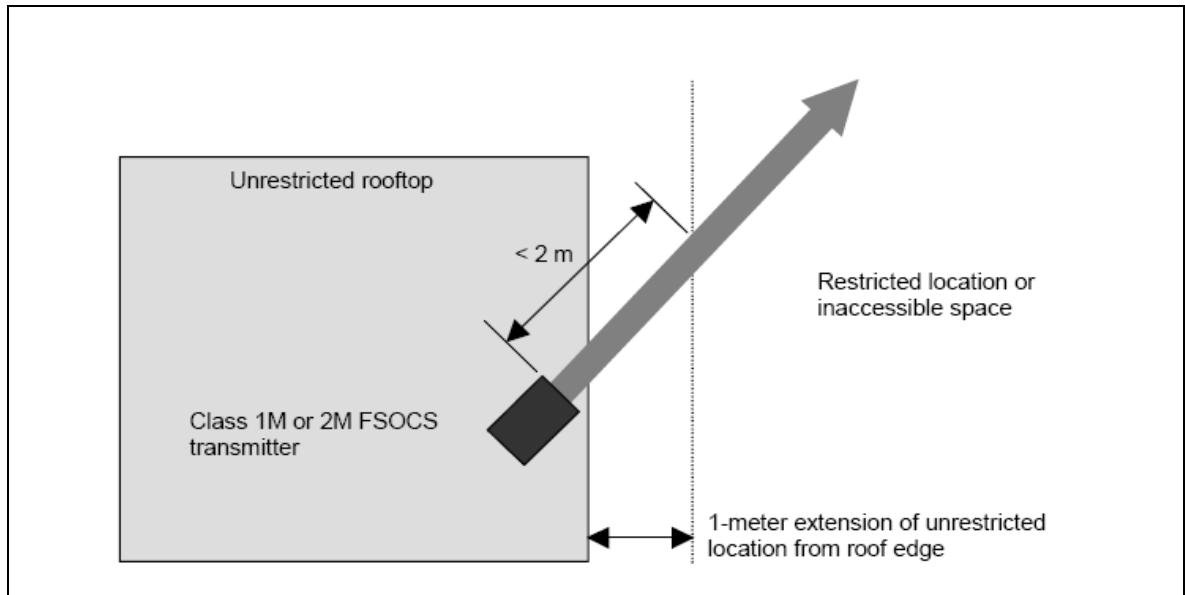


Figure 4.5 – Class 1M or 2M Transmitter Near Edge of Rooftop (Unrestricted Location)

4.4.2.1.2 Use of Class 3R Equipment in Unrestricted Locations. Installation and use of a Class 3R FSOCS transmitter in an unrestricted location is permitted if the following conditions are satisfied:

- a) The transmitter shall be installed and comply with at least one of the following:
 1. Exposure of the eye within the NHZ or the use of optical aids within the ENHZ are not reasonably foreseeable events, or
 2. The transmitter incorporates an interlock connector that is interfaced with an IPS at the time of installation so that the accessible energy is limited to Access Level 1 or 2 as indicated in Figure 4.4.
- b) The installation shall ensure that there is no laser energy reflected back into the unrestricted location (from a window for example) that exceeds Access Level 1 or 2; and
- c) The transmitter and/or shielding shall require a special tool to move/remove it, and a label is visible to warn of the hazard before and after the transmitter or shielding is displaced. Alternatively, the transmitter and/or shielding shall be equipped with an interlock.

4.4.2.2 Requirements for Restricted Locations. Restricted locations are those areas that are inaccessible by the general public but that are accessible to authorized personnel that may not have laser safety training. Where optically-aided viewing conditions are reasonably foreseeable, a suitable area warning sign shall be provided as indicated in Table 4.1.

Examples of interior restricted locations are: Equipment cabinets and closets (cupboards) in offices and industrial buildings and locked/dedicated rooms. Interior restricted locations could

be occupied by service/maintenance personnel or escorted visitors without FSOCS laser safety training.

Restricted locations also exist outdoors. The restricted location on the exterior sides of a building extends outward 2.5 m from the exterior surfaces, balconies or stairways of the building as shown in Figure 4.3. Examples of exterior restricted locations are: limited access areas of commercial or industrial rooftops, telephone poles, or areas where scaffolding might exist. Exterior restricted space could be occupied by window cleaners or service/maintenance personnel without FSOCS laser safety training.

Exterior locations are also considered restricted if either of the following conditions is satisfied:

- a) The location is within the range of 3-6 meters above a surface in an unrestricted location, or
- b) The location is within 2.5 meters in horizontal spacing from any unrestricted location and, if applicable, is greater than 3 meters above the surface of any underlying unrestricted location.

FSOCS optical signals crossing into or received in a restricted location shall not exceed Access Level 1M or 2M, i.e., below the MPE values without optical aids.

The open beam laser transmitters that are used in an FSOCS and are installed without added conditions in restricted locations shall be Class 1, 2, 1M or 2M.

4.4.2.2.1 Use of Class 3R Equipment in Restricted Locations. Installation and use of Class 3R transmitters in restricted locations is permitted if the following conditions are satisfied:

- a) The transmitter shall be installed and comply with at least one of the following:
 - 1. An eye exposure within the NHZ is not a reasonably foreseeable event, or
 - 2. The transmitter shall provide an interlock connector that shall be interfaced with an IPS at the time of installation so that the access level shall be limited to Access Level 1, 2, 1M or 2M as indicated in Figure 4.6.
- b) The installation shall ensure that there is no laser energy reflected back into the restricted location (from a window for example) that exceeds Access Level 1M or 2M;
- c) The transmitter and/or shielding shall require a special tool to move/remove it, and a label that is visible to warn of the hazard before and after the transmitter or shielding is displaced. Alternatively, the transmitter and/or shielding shall be equipped with an interlock; and
- d) Any additional spillover beyond the receiving terminal within the ENHZ shall be within the restricted location, or if in unrestricted location must comply with conditions in 4.2.1.1.

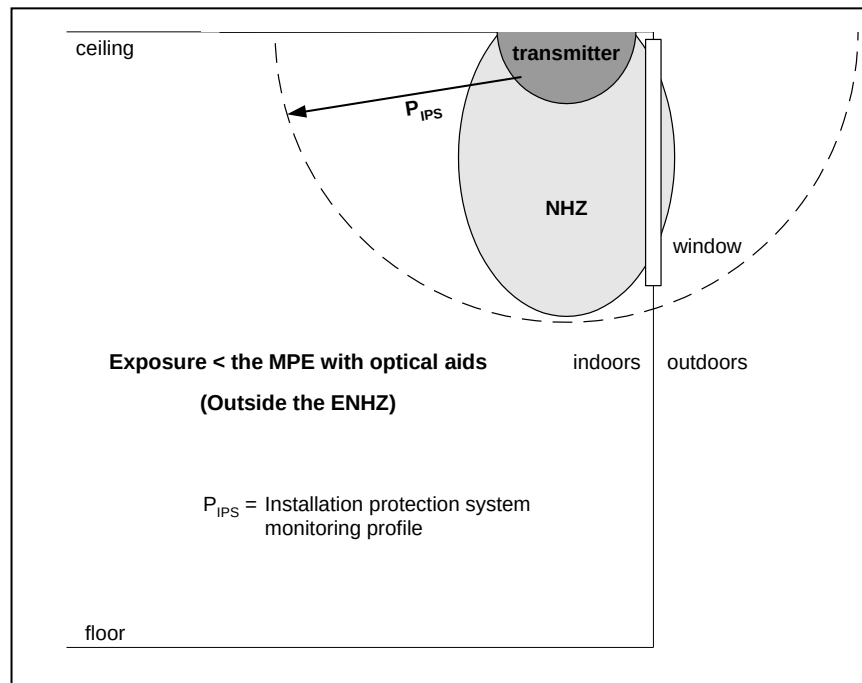


Figure 4.6 – Class 3R transmitter in Restricted Location: An Example of an IPS that Monitors the Entire NHZ of the Class 3R Transmitter

NOTE 1—In this example the power is reduced to the MPE for optically-unaided viewing if human access is detected within the monitored volume.

NOTE 2—Additional care must be taken to monitor the NHZ when it extends from indoors to outdoors.

4.4.2.3 Requirements for Controlled Locations. Controlled locations are those areas that are normally inaccessible except to authorized personnel with appropriate laser safety training, e.g., tower-mounted terminals, fenced/secure areas of rooftops, locked rooms with strictly-controlled access.

Installation and use of Class 1, 2, 1M, 2M and 3R transmitters is permitted in controlled locations without added conditions. FSOCS emissions crossing into or received in controlled locations shall not exceed Access Level 1M, 2M or 3R except as described in 4.4.2.3.1.

4.4.2.3.1 Use of Class 3B and Class 4 Equipment in Controlled Locations. Generally, installation and use of FSOCS equipment in a manner that avoids Access Levels 3B and 4 is preferred. However, provided the zone where Access Level 1M, 2M or 3R is exceeded is confined to a controlled location, industry standard safe practices, e.g., ANSI Z136.1, are permitted to prevent human exposure to Access Levels 3B and 4. Note that Access Levels 3B or 4 are not permitted outside of a controlled location.

Open beam laser transmitters of Class 3B and 4 may be installed and used in controlled locations if the following conditions are satisfied:

- a) An IPS is in place that detects human entry to a volume containing the entire portion of the NHZ that extends outside of the boundaries of the controlled location and causes reduction of the power of the laser to a specified level within a specified time, (see 4.4.3.2.1).

NOTE—When determining an NHZ, care should be taken to include sources of error or beam misdirection.

- b) If the receiving terminal is located within the NHZ, any spillover within the NHZ shall also be contained in a controlled location.
- c) Any additional spillover beyond a receiving terminal within the ENHZ shall not enter an unrestricted location unless conditions of 4.4.2.1.2 are met.
- d) An LSO from the operating organization shall be responsible for establishing and implementing control measures for laser hazards within the controlled location.

4.4.2.4 Requirements for Inaccessible Space. Inaccessible space includes all space that is in neither unrestricted, restricted, nor controlled locations. This space extends outward horizontally from

- a) 2.5 meters from the exterior surfaces of all buildings, or 3.5 meters from locations that may be occupied, e.g., balconies, stairways or openable windows, of all buildings or
- b) The boundaries of restricted locations, and extends upward vertically either 6 meters above a surface in an unrestricted location, or 3 meters above a surface in a restricted location. These conditions are indicated in Figure 4.3.

Access to FSOCS optical radiation in inaccessible space shall not exceed Access Level 1M, 2M or 3R. If the NHZ from an FSOCS transmitter intercepts navigable airspace, the appropriate aviation authorities should be notified (see ANSI Z136.6).

4.4.3 Engineering Controls

4.4.3.1 Cable Connectors

Unrestricted locations: All systems operating in unrestricted locations in which cable connectors are accessible require the use of a tool for access or disconnection if Hazard Level 1 can be exceeded.

Controlled locations: All systems operating in controlled locations in which cable connectors are accessible require the use of a tool for access or disconnection if Hazard Levels 1M, 2M and 3R are exceeded.

The positioning of the connector in a way that prevents human access to a higher hazard level is an acceptable feature to ensure that these requirements are met.

4.4.3.2 Installation Protection System (IPS). An IPS is a feature that functions similarly to an APR system but is not integrated with an FSOCS transmitter by a manufacturer. Instead, an installer may incorporate an IPS with an FSOCS transmitter so that the accessible power at defined locations is reduced to a specific level within a specific time whenever there is an event that could result in human exposure to radiation above the applicable MPE. Unlike the basis of an APR system, the transmitter classification may not be determined based on the operation of an IPS. The interface between the IPS and the FSOCS transmitter shall be through an interlock connector that is provided by the transmitter manufacturer or by equivalent means. FSOCS transmitters that do not provide an interlock connector or equivalent shall not be installed with an IPS.

4.4.3.2.1 IPS Performance Requirements. An IPS shall accomplish the following:

- a) Monitor the entire NHZ or ENHZ depending on the reduced access level.
 - b) Detect human interception of the NHZ or ENHZ, as appropriate, and reduce accessible power to a specified level within the specified time.
 - c) During the 2-second period allowed for power reduction, ensure that the MPE without optical aids at the point of interception shall not be exceeded for a Class 1, 2, 1M or 2M transmitter.
 - d) Be single fault tolerant when the safety function of the IPS is performed, e.g., when single faults of all non-IPS elements of the system occur that could permit an accessible energy above Access Level 1 or 2 within the ENHZ for Class 1 or 2 products, or Access Level 1M or 2M within the NHZ for Class 1M or 2M products.
 - e) Provide an IPS override, for installation or servicing work, that prevents resumption of normal operation while enabled and an indicator that clearly shows that the IPS has been overridden, (based on interlock requirements from IEC 60825-1).
 - f) For transmitters that would be Class 3B or 4 without an IPS, a single fault in the safety function of the IPS system shall cause:
 - 1. Reduction of transmitter emission level within 2 seconds of fault occurrence to Class 1 or 2 if installed in an unrestricted location or to Class 1, 2, 1M or 2M if installed in either a restricted or controlled location (during the 2-second reduction period, the optically unaided MPE shall not be exceeded), and
 - 2. Notification of the single fault condition to the operating organization by means of a required network monitoring system.
- NOTE—If power reduction occurs in less than 2 seconds, the MPE for that duration may be used.
- g) If an IPS is used to reduce the access level at any location, the proper operation of the IPS should be verified periodically.⁸

In some complex systems, where the optical output is dependent on the integrity of other components and the performance of circuit design and software, it may be necessary to use other recognized methods for hazard/safety assessment (see Appendix B).

Once the IPS determines a safe condition, full power operation of the transmitter is permissible.

NOTE—Classification and access level evaluation of the IPS/APR-based FSOCS shall account for start up and restart conditions for all applicable time bases. Until a safe condition is established, the appropriate emission/exposure limits for its installed location type shall not be exceeded.

If an IPS is used to reduce the access level at any location, the proper operation of the IPS should be verified. In circumstances where it is difficult to carry out direct measurements, an assessment of the access level based on calculations may be acceptable. Faults that result in the emission of radiation in excess of the applicable AEL for a limited period only, and for which it

⁸ Generally the reliability of APR and IPS falls upon the manufacturer of the components and would be covered by their fault analysis requirements.

is not reasonably foreseeable that human access to the radiation will occur before the product is taken out of service or adjusted down below the AEL, need not be considered.

The FSOCS 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. 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.

4.4.3.3 Area Warning Signs and Labels. Table 4.1 shows the requirements for area warning signs and labels for the access levels and location types.

Table 4.1 – Requirements for Area Warning Signs

Access Level	Location type		
	Unrestricted	Restricted	Controlled
1	None	None	None
2	None	None	None
1M^a	Adjacent ^b	Adjacent	Adjacent
2M^a	Adjacent ^b	Adjacent	Adjacent
3R	Adjacent ^b	Adjacent ^b	Adjacent & Entrance
3B	Not permitted	Not permitted	Adjacent & Entrance
4	Not permitted	Not permitted	Adjacent & Entrance

^a For Access Level 1M or 2M, the area warning sign shall include the statement: “Do not use binoculars, telescopes or other optical aids.”

^b Subject to installation conditions described in 4.2.1.1, 4.2.1.2 or 4.2.2.1.

4.4.3.4 Additional Manufacturer’s Instructions. In the installation manual, the manufacturer shall explicitly define the area location type per the definitions of this standard, and state whether the FSOCS is intended for installation in an unrestricted, restricted, or controlled access location type. The installation manual shall include the following statement:

CAUTION – Use of controls, or adjustments, or performance of procedures other than those specified herein may result in hazardous optical radiation exposure.

In addition, the following statements that apply to the particular classification of the transmitter of the FSOCS shall be included in the installation manual:

Class 1 FSOCS transmitters:

This is a Class 1 FSOCS transmitter and may be installed in unrestricted, restricted, or controlled locations as defined in this manual.

Class 1M FSOCS transmitters:

Caution, this is a Class 1M FSOCS transmitter and may be installed in unrestricted, restricted, or controlled locations as defined in this manual. See installation constraints for use in unrestricted locations.

Class 2 FSOCS transmitters:

Caution, this is a Class 2 FSOCS transmitter and may be installed in unrestricted, restricted, or controlled locations as defined in this manual.

Class 2M FSOCS transmitters:

Caution, this is a Class 2M FSOCS transmitter and may be installed in unrestricted, restricted, or controlled locations as defined in this manual. See installation constraints for use in unrestricted locations.

Class 3R FSOCS transmitters:

Caution, this is a Class 3R FSOCS transmitter and may be installed in unrestricted, restricted, or controlled locations as defined in this manual. See installation constraints for use in unrestricted and restricted locations.

Class 3B FSOCS transmitters:

Caution, this is a Class 3B FSOCS transmitter and may be installed in controlled locations as defined in this manual.

Class 4 FSOCS transmitters:

Caution, this is a Class 4 FSOCS transmitter and may be installed in controlled locations as defined in this manual.

The equipment labels shall be located in plain view on the equipment in the vicinity of the connectors, e.g., outlets, patch panels, patch cords.

4.4.3.5 Specular Reflections. When installing and operating an FSOCS, care should be exercised to prevent unintentional reflection (total and/or partial) of the primary and, if used, beacon or alignment transmitter beams. (This should apply to all laser classes as a matter of good work practice.) The possibility of accidental misdirection of the laser beam and unintentional reflections shall be taken into account in the evaluation of the access level and NHZ, as appropriate, by the system installer/operating organization.

4.4.4 Administrative Controls

4.4.4.1 Optical Fiber Cables Associated with FSOCS. If an optical fiber cable should become disconnected or accidentally break, the following practices should be followed:

- a) Do not examine, look directly at or stare into broken, severed or disconnected optical fibers or cables.
- b) De-energize the affected part of the FSOCS if the means to do so is clear.
- c) Arrange for a trained service person to de-energize the FSOCS and repair or replace the optical fiber or cable.

4.4.4.2 Installation. All installation and service operations of Hazard Level 1M, 2M, 3R in unrestricted and restricted locations shall follow procedures set forth in 4.3.

4.4.4.3 Controlled Locations. Controlled locations are those whose occupancy is subject to control and supervision for the purpose of protection against optical radiation hazards. Some FSOCS installations or service conditions, e.g., splicing, removal of optical connectors, may result in accessible emission. Under these conditions the following administrative and procedural controls should be followed:

- a) Only authorized, trained personnel shall be permitted to install or perform service on Access Level 1M, 2M, 3R or 3B FSOCS or on Hazard Level 1M, 2M, 3R or 3B optical fiber portions of the FSOCS.
- b) Working on energized systems should be avoided whenever possible. An appropriate procedure for de-energizing systems should be in place so that the system is not re-activated during maintenance and/or service procedures.
- c) Only authorized, trained personnel shall be permitted to use Hazard Level 1M, 2M, or 3R FSOCS test equipment during installation or service.
- d) All unauthorized personnel shall be excluded from the NHZ of Access Level 3B FSOCS during installation and service when there is a possibility that these systems may become energized.
- e) The degree and level of education and training on safety concepts and procedures shall be in accordance with Section 5.
- f) Eye protection devices which are specifically designed for protection against the optical energy from a Access Level 3B FSOCS should be administratively required when engineering or other procedural administrative controls are inadequate to eliminate potential exposure in excess of the applicable MPE. Eye protection shall be worn during service or installation of an Access Level 4 FSOCS.

5. Safety and Training Programs

5.1 Organizations

The installation or operating organization management shall establish and maintain an adequate program for the control of OCS hazards. Safety and training programs should be instituted for all personnel who install or service Access Level and Hazard Level 1M/2M/3R OCS. Safety and training programs shall be instituted for all personnel who service or install Access Level and Hazard Level 3B OCS and for systems where the access level or hazard level is unknown or uncertain. If a safety and training program is instituted, it shall be directed by individuals competent in the field of laser and OCS safety. The program shall provide:

- a) Background information on laser safety
- b) Background on laser and LED-based OCS
- c) Safety information on OCS hazard levels
- d) Guidance on the safe use, installation and service of OCS and the adequacy of safety practices
- e) NOHD and NHZ information for Access Level and Hazard Level 3B OCS

5.2 Training

The training program shall enable technicians, installers and service personnel to maintain a safe work environment. Service personnel shall be instructed periodically on the safety precautions, procedures and practices that are applicable to OCS and on safety measures that will ensure, insofar as possible, that OCS and any associated test equipment are properly operated and controlled to protect transient or uninformed people.

5.2.1 Training of the Safety-Qualified OCS Installer. The individual who is the key installer or supervisor of the installation team shall be sufficiently trained in all aspects of the safety requirements for site evaluation and installation of the specific OCS. If new and different transmitters are to be installed, additional system-specific training is required.

5.3 Responsibilities of Individuals Working with OCS

Each person engaged in the installation and service of OCS is responsible for:

- a) Observing all rules, procedures and practices established for the safe operation of OCS.
- b) Notifying supervision immediately of conditions or practices that have the potential to cause personal injury or property damage.
- c) Reporting immediately to supervision any known or suspected abnormal exposure to optical radiation.

6. Medical Examinations and Medical Surveillance

6.1 Medical Examinations

A medical surveillance program should be considered for OCS personnel assigned to work routinely on energized Access Level 3B FSOCS or Hazard Level 3B or 4 OFCS and whose job requires disconnecting optical connectors, using Class 3B optical test equipment such as loss test sets, optical time domain reflectometers or Class 1 test sets used on OFCS containing Class 3B or 4 amplifiers, or performing splicing operations on Hazard Level 3B systems. These personnel should have a baseline eye examination before starting work in an OCS environment. The recommended examination protocol is described in ANSI Z136.1.

A medical surveillance program is not needed for personnel who work in the general vicinity of OFCS and FSOCS but who are not routinely within the NOHD or NHZ of an emitting optical fiber or the beam of an FSOCS transmitter. (See Appendix E for further information.)

6.2 Medical Examinations Following Suspected Injury

Medical examinations shall be performed as soon as practical (usually within 48 hours) when a suspected injury or adverse effect from a laser exposure occurs. In addition to the acute symptoms, consideration shall be given to the exposure wavelength, emission characteristics and exposure situation to assure appropriate medical referral. For injury to the eye from lasers operating in the retinal hazard region, examinations shall be performed by an ophthalmologist.

The eye examination is not designed to be part of a complete medical examination in which the total visual system is evaluated. The particular visual parameters selected for measurement/examination are those deemed necessary for the particular job and/or those which may be affected by hazardous exposure to OCS radiation. See ANSI Z136.1 for additional information.

7. Non-beam Hazards

7.1 General

Non-beam hazards (NBH) are all hazards arising from the presence of a laser system, excluding direct human exposure to a laser beam. NBH include physical, chemical and biological agents. NBH such as fire or exposure to airborne contaminants may occur when a material is exposed to a laser beam or when materials used to generate the beam are released into the atmosphere; electrocution may occur when individuals contact system components. Electrocution and fire can be life threatening and its prevention may require use of more stringent control measures than those discussed in Section 4. Due to the diversity of the NBH, the LSO may need to seek the assistance of safety or industrial hygiene personnel.

7.2 Glass Particle Hazards

There is a real risk of direct injury to OFCS workers performing cleaving operations. This injury is caused by small lengths of glass fibers going into the tips of fingers or the facial area and personnel must be warned of this hazard. The use of protective guards or shields can help to minimize this exposure. If there is poor housekeeping in the areas where these operations are performed, the problem becomes worse. The use of tape to pick up small fragments of glass after such operations can help minimize this issue. Care must be taken when using fans or exhaust systems to capture small sharp fragments; if such fragments become airborne they may create additional concerns. To avoid injury to others, fiber shards should be disposed of appropriately, e.g., wrapped in tape prior to disposal. Where practical, a suitable container should be used to collect discarded pieces of fiber to avoid embedment in clothing, the eye or the skin. Eating shall not be permitted in a fiber cleaving operations area.

7.3 Solvents and other Chemicals

Solvents or other chemicals that are used for stripping, cleaning and splicing optical fibers shall be used in adequately ventilated areas. The least hazardous chemicals needed for a task should be used. If the area is not appropriately ventilated then exhaust ventilation systems (including hoods, ducts, air cleaner and fans) should be designed and fabricated in accordance with the latest revisions of the ACGIH "Handbook of Ventilation for Contaminant Control," and ANSI/AIHA "Fundamentals Governing the Design and Operation of Local Exhaust Ventilation Systems," ANSI Z9.2.

Material Safety Data Sheets (MSDS) shall be required for each solvent or chemical being used. Workers shall receive appropriate safety training in the handling and disposal of solvents and chemicals used in this work.

7.4 Optical Curing

Some procedures may require the use of an optical curing system to harden coatings or during connectorization. The use of such systems may require the use of PPE such as gloves, face-shields and special protective eyewear to preclude exposure to visible and UV radiation. In addition, some photosensitizing agents that may be present in the curing compounds can cause or make an individual susceptible to face and skin irritation and other issues. Viewing the unfiltered optical beam may produce harmful ocular effects from the bright visible radiation. In addition, certain curing systems may produce UV at short wavelengths that can create ozone.

7.5 Electrical Hazards

The use of a laser or laser system can present an electrical shock or electrocution hazard from contact with energized electrical conductors during laser set-up or operation where equipment protective covers may have been removed. In addition, workers involved with installing OFCS and FSOCS during inclement weather also increase the potential risk of electrical shock.

7.6 Exposure to Electric and Magnetic Fields

When OFCS are installed on electric utility poles workers may be exposed to current carrying electrical cables and transformers that can generate intense electric and magnetic fields (50 or 60 Hz and harmonics). Information about potential hazards associated with such exposures can be found in the latest revision of ANSI/IEEE “Standard for Safety Levels with respect to Human Exposure to Electromagnetic Fields, 0 to 3 kHz,” IEEE C95.6.

7.7 Fires

The optical power in contemporary OFCS and FSOCS can be greater than 0.5 W and, therefore, a potential fire hazard can be present. Workers need to be aware of this situation and receive training on how to respond if a fire would occur. In fact, under some situations where flammable compounds or substances exist, e.g., certain dusts and gasses, it is possible that fires can be initiated by lower power lasers. The LSO should therefore encourage the use of flame retardant materials whenever appropriate. Refer to NFPA “Standard for Laser fire Protection,” NFPA-115, for further information on controlling laser induced fires.

There have been reports of fires and explosions associated with damaged (leaking) fibers located in a natural gas line. Apparently, there was sufficient laser energy to ignite the gas creating the fire and explosion.

7.8 Falls

The installation, service and maintenance of OFCS or FSOCS may require personnel to work suspended on elevated platforms or on ladders. Such work activities create concern about slips and falls. In addition, workers in such unique locations can be exposed to situations that may evoke startle reactions, afterimages and temporary flash blindness scenarios that can create distractions that lead to other effects of a more serious nature, e.g., falls. As applicable, the LSO shall effect conformance with OSHA fall protection requirements such as 29 CFR 1910.268 for the telecommunications industry, as well as consensus standards, e.g., ANSI

“Safety Requirements for Workplace Walking/Working Surfaces and Their Access; Workplace Floor, Wall and Roof Openings; Stairs and Guardrail Systems,” ANSI A1264.1-2007.

7.9 Confined Space

The installation, service and maintenance of OFCS or FSOCS may require personnel to work or enter confined space. As applicable, the LSO shall affect conformance with OSHA confined space requirements as well as any consensus standards that apply.

8. Criteria for Exposure of the Eye and Skin

Maximum permissible exposure (MPE) values are below known hazardous levels. However, exposure to levels at the MPE may be uncomfortable to view or feel upon the skin. Thus, it is good practice to maintain exposure levels to well below the MPE.

The MPE values shown in Table 5a and Table 5b are expressed (normalized) relative to a limiting aperture area. The limiting aperture is the maximum circular area over which irradiance and radiant exposure are averaged for purposes of hazard level classification or hazard analysis. (See Table 4a for the limiting aperture for the determination of access level and Table 4b for the limiting aperture for the determination of hazard level.)

The irradiance values for the MPEs in Table 5a and Table 5b (with the appropriate correction factors in Table 7 applied) can be obtained by dividing the radiant exposure by the exposure duration t , in seconds. Values for the radiant exposure can be obtained by multiplying the irradiance by the exposure duration t , in seconds. Values in Table 5a, Table 5b and Table 7 are only provided for wavelengths greater than $0.6\ \mu\text{m}$ and for continuous wave (CW) or for pulsed systems where the PRF exceeds 55 kHz, since these are used predominantly in OCS and installation alignment lasers. For other wavelengths, see ANSI Z136.1.

8.1 Point Source and Extended Source Ocular Exposures

Within the retinal hazard region ($\lambda \leq 1.4\ \mu\text{m}$) sources are considered either point sources (where a 20-30 μm , or minimal retinal image is produced), or extended sources. Whether a source is considered a point source or an extended source depends on the on the apparent visual angle (angular subtense of the source, α) of the source (determined at the viewing distance or 10 cm, whichever is greater). Specifically, point sources subtend a visual angle less than $\alpha_{\min}$ (1.5 mrad); extended sources subtend an angle $\geq \alpha_{\min}$.

NOTE—The angular subtense, α , is the apparent visual angle as calculated from the source size, e.g., mode field diameter for single-mode fibers, and distance from the eye – the source size is neither the diameter of the fiber nor the divergence of the beam emitted by the source.

Intrabeam ocular viewing of a single laser or LED source or a single fiber is always considered to be a point source exposure. Diffuse reflections or multiple source viewing of certain multiple laser diode or LED arrays, OFCS cables comprised of two or more individual optical fibers, or multi-fiber connectors, may be either an extended source or point source exposure depending on the angular subtense of the source.

Non-uniform extended sources such as multiple laser diodes or LEDs, OFCS cables comprised of two or more individual optical fibers or multi-fiber connectors, require special considerations if $\alpha > \alpha_{\min}$. Each independent subsources of the extended source shall be first considered a point source and the results compared with the corresponding MPE. Then, the entire source (or any combination of subsources) shall be considered an extended source and the results compared with the extended source MPE. (See B.3.2.6.5 in Appendix B.) The most restrictive results shall apply. Any combination of sources whose centers are separated by an angle greater than $\alpha_{\max}$ (100 mrad) are considered independent.

NOTE—While a broken, rather than cleaved or cleanly-cut, ribbon cable may still be considered an extended source, the random emission patterns from fractured fibers reduces the hazard to that of the single worst-case (highest hazard level) fiber in the cable.

The MPE for ocular exposure contains a correction factor C_E . For point source viewing, e.g., most FSOCS, the correction factor C_E is 1.0. When viewing certain laser diode or LED arrays, OFCS cables comprised of two or more individual optical fibers, or multi-fiber connectors, extended source criteria may apply. When $\alpha > \alpha_{\min}$, i.e., when extended source criteria apply, the MPE correction factor C_E is greater than 1.0. When $\alpha_{\min} < \alpha \leq 100$ mrad, C_E is equal to $\alpha/\alpha_{\min}$; when $\alpha > 100$ mrad, C_E is equal to $\alpha^2/(\alpha_{\min} \alpha_{\max})$. (See Table 7 for values of $\alpha_{\min}$.)

8.2 MPE for Ocular Exposures

The single pulse or single exposure MPE values for ocular exposures are given in Table 5a and Table 5b. Table 5a can be used as a default as the MPE values listed are worst-case. Table 5b provides relaxed MPE values associated with the effects of extended source viewing. In order to apply these MPE values, the information in the remainder of 8.2 is required.

When a laser emits radiation at several widely different wavelengths, or where pulses are superimposed on a CW background, the MPE calculations are complex. The effects of simultaneous exposure to pulses and CW radiation are not strictly additive (there may be synergism), and caution should be used in these exposure situations until more data are available.

8.2.1 Wavelength. The wavelength, λ , must be specified to establish which spectral region is applicable. The MPEs in Tables 5, 6 and 7 are arranged in broad wavelength regions. For multiple wavelength laser emissions, the MPE must first be determined for each wavelength separately. Simultaneous exposure to several wavelengths is additive on a proportional basis of spectral effectiveness with due allowance for all correction factors. (See 3.2.2.2.)

8.2.2 Exposure Duration. For a CW visible (0.6 μm to 0.7 μm) source, the exposure duration is the maximum time of anticipated direct exposure, $T_{\max}$. If deliberate staring into the beam is not intended or anticipated, the aversion response time, 0.25 s, may be used.

For non-visible wavelengths (greater than 0.7 μm), the CW exposure duration is the maximum time of anticipated direct exposure, $T_{\max}$. For the hazard evaluation of retinal exposures in the near infrared (0.7 μm to 1.400 μm), $T_{\max}$ of 10 s provides an adequate hazard criterion for either incidental viewing or purposeful staring conditions for viewing point sources. In this case, eye movements provide a natural exposure limitation, eliminating the need for calculations based on exposure durations greater than 10 s, except for unusual viewing conditions. For extended sources T_2 , as presented in Table 7, shall be used.

8.2.3 Repeated Exposures. Any injury from lasers used for OCS (0.6 μm to 1.5 μm) would be caused by thermal damage. Exposures exceeding T_2 (generally 10 s – see Table 7) do not increase the risk of injury. MPEs are therefore expressed as a constant irradiance for these exposures. Therefore, repeated exposures throughout a period of time, e.g., a workday, are not cumulative.

The three rules to determine the MPE for exposure to a multiple-pulse laser are found in ANSI Z136.1. Rule 1 protects against thermal injury from any single pulse having greater than average energy, Rule 2 protects against heat buildup from average power for thermal injury, and Rule 3 protects against sub-threshold pulse-cumulative thermal injury.

Although optical signals used with telecommunications systems are modulated, the modulating frequencies are usually greater than 1 MHz and CW conditions apply. For systems that are modulated at lower frequencies, see ANSI Z136.1.

8.3 Skin Exposure

Under normal conditions, exposure of the skin to the emission from an FSOCS will be at levels below the skin MPEs found in ANSI Z136.1. It may be possible, however, especially in OFCS that contain optical amplifiers, to exceed these MPEs at extremely short distances from the end of the fiber. Although skin injury would be unlikely unless it is Hazard Level 4, touching the end of any optical fiber should be avoided. See Table 6 for skin MPE values.

9. Measurements

9.1 General

The procedures included in this standard are designed to minimize the need for irradiance measurements. For OFCS, it is generally sufficient to measure the power (when not known) in the fiber (closed-system measurement) since the AELs and potential exposures are related to this quantity. Normally, a potential hazard exists only when the end of an energized fiber is exposed during installation, service or during some splicing operations. In such cases, protective measures should be followed since the power level and wavelength of the OFCS transmitters or test sets may not be known. Similarly, if the beam parameters of an FSOCS are accurately known, including the beam divergence, it is generally sufficient to measure the optical power at the output optics of the transmitter. If irradiance measurements are to be performed, the measurement process may be difficult, particularly when OCS operates at widely different wavelengths. In addition to different ocular hazards associated with different wavelengths, the detector may respond differently to the different wavelengths. Measurements for hazard level classification or hazard evaluation should only be undertaken by personnel experienced in optical fiber and laser metrology.

9.2 Measurements of Optical Power

If measurements are performed, the accuracy of the instrumentation should be traceable to an acceptable national standard, either directly to the National Institute of Standards and Technology (NIST) or to other transfer standards traceable to NIST (NIST maintains a program

for these purposes) and the instrument should be current with respect to the required calibration date.

Measurements of the optical power emitted from the end of an optical fiber should ensure that all optical power is collected, not just the power within the angle defining the numerical aperture. A variety of specialized OFCS power meters have been developed and are commercially available. Optical power measurements for hazard classification for the purposes of this standard require the collection of total power (optical flux) within the defining aperture placed at the defined distance from the fiber tip (or FSOS aperture) as specified in Table 4c.

10. Revision of Standards and Codes Referred to in this Document

When any of the following American National Standards referred to in this document is superseded by a revision approved by the American National Standards Institute, Inc., the revision shall apply:

10.1 ANSI Standards

American National Standard for Safe Use of Lasers, ANSI Z136.1.

American National Standard for Safe Use of Lasers Outdoors, ANSI Z136.6.

American National Standard Fundamentals Governing the Design and Operation of Local Exhaust Ventilation Systems, ANSI/AIHA Z9.2.

American National Standard Recommended Practice for Laser Safety Measurements for Hazard Evaluation, ANSI Z136.4.

American National Standard Safety Requirements for Workplace Walking/Working Surfaces and Their Access; Workplace Floor, Wall and Roof Openings; Stairs and Guardrail Systems, ANSI A1264.1.

10.2 Other Standards and Codes

ACGIH, Handbook of Ventilation for Contaminant Control.

FDA/CDRH Federal Laser Product Performance Standard (FLPPS), 21CFR Part 1040.

FDA/CDRH Laser Products – Conformance with IEC 60825-1 and IEC 60601-2-22; (Laser Notice No. 50).

IEC 60825 Safety of Laser Products – Part 1: Equipment Classification, Requirements, and User's Guide.

IEC 60825 Safety of Laser Products – Part 2, Safety of Optical Communication Systems.

IEC 60825 Safety of Laser Products –Part 12: Safety of Free Space Optical Communication Systems used for Transmission of Information.

IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0 to 3 kHz, IEEE C95.6-2002.

NFPA 115 Standard for Laser fire Protection.

OSHA Occupational Safety and Health Standards for General Industry, 29 CFR

1910.147 The Control of Hazardous Energy (lockout/tagout)

1910.268 Telecommunications

**Table 1 – Accessible Emission Limits for
Class 1 and Class 1M OCS Laser Products**

Wavelength (μm)	Exposure Duration (s)	Radiant Energy (J)	Radiant Power (W)	Radiant Exposure ($\text{J}\cdot\text{cm}^2$)	Irradiance ($\text{W}\cdot\text{cm}^2$)
0.600 to 0.700	1×10^{-3} to 10	$7 \times 10^{-4} t^{0.75} C_E$			
0.600 to 0.700	10 to T_2	$7 \times 10^{-4} t^{0.75} C_E$			
0.600 to 0.700 ^a	T_2 to 3×10^4		$3.9 \times 10^{-4} C_E$		
0.600 to 0.700 ^b	T_2 to 3×10^4		$7 \times 10^{-4} T_2^{-0.25} C_E$		
0.700 to 1.050	1×10^{-3} to 10	$7 \times 10^{-4} t^{0.75} C_A C_E$			
0.700 to 1.050	10 to T_2	$7 \times 10^{-4} t^{0.75} C_A C_C C_E$			
0.700 to 1.050 ^a	T_2 to 3×10^4		$3.9 \times 10^{-4} C_A C_E$		
0.700 to 1.050 ^b	T_2 to 3×10^4		$7 \times 10^{-4} T_2^{-0.25} C_A C_C C_E$		
1.050 to 1.400	1×10^{-3} to 10	$3.5 \times 10^{-3} t^{0.75} C_C C_E$			
1.050 to 1.400	10 to T_2	$7 \times 10^{-4} t^{0.75} C_A C_C C_E$			
1.050 to 1.400 ^a	T_2 to 3×10^4		$3.9 \times 10^{-4} C_A C_E$		
1.050 to 1.400 ^b	T_2 to 3×10^4		$7 \times 10^{-4} T_2^{-0.25} C_A C_C C_E$		
1.400 to 1.500	0.1 to 0.35	$4.4 \times 10^{-3} t^{0.25}$			
1.400 to 1.500	0.35 to 10	$10^{-2} t$			
1.400 to 1.500	10 to 3×10^4		10^{-2}		
1.500 to 1.800	0.1 to 0.35	8×10^{-3}			
1.500 to 1.800	0.35 to 10	$1.8 \times 10^{-2} t^{0.75}$			
1.500 to 1.800	10 to 3×10^4		10^{-2}		
1.800 to 4.000	0.1 to 0.35	$4.4 \times 10^{-3} t^{0.25}$			
1.800 to 4.000	0.35 to 10	$10^{-2} t$			
1.800 to 4.000	10 to 3×10^4		10^{-2}		
4.000 to 10^3	0.1 to 10			$0.56 t^{0.25}$	
4.000 to 10^3	10 to 3×10^4				0.1
NOTE 1—See Table 7 for correction factors C_A , C_C , C_E and T_2 .					
NOTE 2—The hazard levels and access levels in this standard are analogous to the hazard Classes, 1, 1M, 2, 2M, 3R and 3B. This approach is consistent with that of ANSI Z136.1-2007, IEC 60825-2 (2004), and IEC 60825-12 (2004).					
NOTE 3—Accessible Emission Limits (AELs) are used to determine hazard classification, hazard levels, and access levels. This level of power or energy entering the eye is not expected to cause injury. For clarification of the terms access level and hazard level as used in this standard, see Appendix D.					
NOTE 4—The values shown in Tables 1-5b represent selected values commonly used with OCS laser systems. To determine values for other laser systems, refer to ANSI Z136.1 or IEC 60825-1.					
NOTE 5—The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$, e.g., 315 to 400 nm means $315 \leq \lambda < 400$ nm.					

^a $\alpha \leq 1.5$ mrad

^b $\alpha > 1.5$ mrad

Table 2 – Accessible Emission Limits for Class 2 and Class 2M OCS Laser Products

Wavelength (μm)	Exposure Duration (s)	Radiant Energy (J)	Radiant Power (W)
0.600 to 0.700	$t < 0.25$	$7 \times 10^{-4} t^{0.75} C_E$	
	$t \geq 0.25$		$C_C \times 10^{-3}$

NOTE—The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$.

Table 3a – Accessible Emission Limits for Class 3R OCS Laser Products

Wavelength (μm)	Exposure Duration (s)	Radiant Energy (J)	Radiant Power (W)	Radiant Exposure ($\text{J}\cdot\text{cm}^2$)	Irradiance ($\text{W}\cdot\text{cm}^2$)
0.600 to 0.700	1×10^{-3} to 0.25	$3.5 \times 10^{-3} t^{0.25} C_E$			
0.600 to 0.700	$t \geq 0.25$ to 3×10^4		$5.0 \times 10^{-3} C_E$		
0.700 to 1.050	1×10^{-3} to 10	$3.5 \times 10^{-3} t^{0.75} C_A C_E$			
0.700 to 1.050	10 to T_2	$3.5 \times 10^{-3} t^{0.75} C_A C_C C_E$			
0.700 to 1.050 ^a	T_2 to 3×10^4		$2.0 \times 10^{-3} C_A C_E$		
0.700 to 1.050 ^b	T_2 to 3×10^4		$3.5 \times 10^{-3} C_A C_C C_E T_2^{-0.25}$		
1.050 to 1.400	1×10^{-3} to 10	$1.8 \times 10^{-2} t^{0.75} C_A C_E$			
1.050 to 1.400	10 to $t T_2$	$3.5 \times 10^{-3} t^{0.75} C_A C_C C_E$			
1.050 to 1.400	T_2 to 3×10^4		$2.0 \times 10^{-3} C_A C_E$		
1.050 to 1.400	T_2 to 3×10^4		$3.5 \times 10^{-3} C_A C_C C_E T_2^{-0.25}$		
1.400 to 1.500	1×10^{-3} to 0.35	$2.2 \times 10^{-2} t^{0.25}$			
1.400 to 1.500	0.35 to 10	$5 \times 10^{-2} t$			
1.400 to 1.500	10 to 3×10^4		5×10^{-2}		
1.500 to 1.800	1×10^{-3} to 0.35	4×10^{-2}			
1.500 to 1.800	0.35 to 10	$9 \times 10^{-2} t^{0.75}$			
1.500 to 1.800	10 to 3×10^4		5×10^{-2}		
1.800 to 4.000	1×10^{-3} to 0.35	$2.2 \times 10^{-2} t^{0.25}$			
1.800 to 4.000	0.35 to 10	$5 \times 10^{-2} t$			
1.800 to 4.000	10 to 3×10^4		5×10^{-2}		
4.000 to 10^3	1×10^{-3} to 10			$2.8 t^{0.25}$	
4.000 to 10^3	10 to 3×10^4				0.5
NOTE 1—See Table 7 for correction factors C_A , C_C , C_E , and T_2 .					
NOTE 2—The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$.					

^a $\alpha \leq 1.5$ mrad^b $\alpha > 1.5$ mrad

Table 3b – Accessible Emission Limits for Class 3B OCS Laser Products

Wavelength (μm)	Exposure Duration (s)	Radiant Energy (J)	Radiant Power (W)
0.600 to 0.700	1×10^{-3} to $t < 0.06$	0.03	
0.600 to 0.700	$0.06 \leq t \leq 3 \times 10^4$		0.5
0.700 to 1.050	1×10^{-3} to $t < 0.06 C_A$	$0.03 C_A$	
0.700 to 1.050	$0.06 C_A \leq t \leq 3 \times 10^4$		0.5
1.050 to 1.400	1×10^{-3} to 0.25	0.15	
1.050 to 1.400	0.25 to 3×10^4		0.5
1.400 to 10^3	1×10^{-3} to 0.25	0.125	
1.400 to 10^3	0.25 to 3×10^4		0.5

NOTE 1—See Table 7 for correction factor C_A .NOTE 2—The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$.NOTE 3—The exposure duration t_1 to t_2 means $t_1 \leq t < t_2$.**Table 4a – Limiting Apertures (Irradiance and Radiant Exposure) for General Hazard Evaluation and the Determination of Access Levels (FSOCS)**

Wavelength (μm)	Duration (s)	Aperture diameter (mm)	
		Eye	Skin
0.600 to 1.400	10^{-3} to 3×10^4	7.0	3.5
	10^{-3} to 0.3^a	1.0	3.5
1.400 to 10^2	0.3 to 10^a	$1.5 t^{0.375}$	3.5
	10 to 3×10^4	3.5	3.5
10^2 to 10^3	10^{-3} to 3×10^4	11.0	11.0

NOTE 1—The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$.NOTE 2—The exposure duration t_1 to t_2 means $t_1 \leq t < t_2$.

^a Under normal conditions these exposure durations would not be used for hazard evaluation. Although optical signals used with telecommunications systems are modulated, the modulating frequencies are usually greater than 1 MHz and CW conditions apply. For systems that are modulated at lower frequencies, see Z136.1. (See Table 4c for measurement conditions.)

Table 4b – Limiting Apertures for General Hazard Evaluation and the Determination of Hazard Levels (OFCS) ^a

Wavelength (μm)	Duration (s)	Measurement Condition	
		Aperture diameter (mm)	Measurement Distance (mm) ^b
0.600 to 1.400	10^{-3} to 3×10^4	7.0	70
	10^{-3} to 0.3	1.0	28
1.400 to 10^2	0.3 to 10^c	$1.5 t^{0.375}$	28
	10 to 3×10^4	3.5	28
10^2 to 10^3	10^{-3} to 3×10^4	11.0	28

NOTE 1—The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$.

NOTE 2—The exposure duration t_1 to t_2 means $t_1 \leq t < t_2$.

^a Hazard levels should not be confused with the classification of the laser product. See Appendix D for clarification.

^b From the closest point of human access to the active end of the fiber, and if the emitting fiber tip is recessed, at that point of human access.

^c Under normal conditions these exposure durations would not be used for hazard evaluation. Although optical signals used with telecommunications systems are modulated, the modulating frequencies are usually greater than 1 MHz and CW conditions apply. For systems that are modulated at lower frequencies, see Z136.1. (See Table 4c for measurement conditions.)

Table 4c – Summary of Measurement Conditions for Classification

	For AELs expressed in power (W) or energy (J)				For AELs expressed as irradiance (W/cm ²) or radiant exposure (J/cm ²)	
Wavelength (μm)	Condition 1 Low divergence (for binoculars – FSOCS) ^a		Condition 2 High divergence (for eye loupes - OFCS) ^a		For MPEs and determination of levels 1M and 2M	
	Aperture (mm)	Distance (mm)	Aperture (mm)	Distance (mm)	Aperture (mm)	Distance (mm)
0.6 to 1.4	50	2000	7	70	7	100
1.4 to 2.8	$7 \times A^b$	2000	7	28	A^b	100
2.8 to 10^2	N/A	N/A	N/A	N/A	A^b	0
10^2 to 10^3	N/A	N/A	N/A	N/A	11	0
NOTE 1—In cases where the source is not accessible by virtue of engineering design, e.g., recessed, the minimum measurement distance would be at the closest point of human access.						
NOTE 2—The measurement distance is defined as the distance from the output aperture of the laser device.						

^a Generally, high divergence beams are at least 5 mrad, and low divergence beams are less than 5 mrad; however, where doubt exists, both conditions should be tested.

^b $A = 1 \text{ mm}$ $t \leq 0.3 \text{ s}$
 $= 1.5 t^{0.375}$ $0.3 \text{ s} < t < 10 \text{ s}$
 $= 3.5 \text{ mm}$ $t \geq 10 \text{ s}$

Table 5a – Maximum Permissible Exposure (MPE) for Point-source Ocular Exposure to an OCS Laser Beam

Wavelength (μm)	Exposure Duration, <i>t</i> (s)	MPE	
		(J·cm ⁻²)	(W·cm ⁻²)
Visible			
0.600 to 0.700	10 ⁻³ to 10	1.8 <i>t</i> ^{0.75} × 10 ⁻³	
0.600 to 0.700	10 to 3 × 10 ⁴		1 × 10 ⁻³
Near Infrared			
0.700 to 1050	10 ⁻³ to 10	1.8 <i>C</i> _A <i>t</i> ^{0.75} × 10 ⁻³	
0.700 to 1050	10 to 3 × 10 ⁴		<i>C</i> _A × 10 ⁻³
1.050 to 1.400	10 ⁻³ to 10	9.0 <i>C</i> _C <i>t</i> ^{0.75} × 10 ⁻³	
1.050 to 1.400	10 to 3 × 10 ⁴		5 <i>C</i> _C × 10 ⁻³
Far Infrared			
1.400 to 1.500	10 ⁻³ to 10	0.56 <i>t</i> ^{0.25}	
1.400 to 1.500	10 to 3 × 10 ⁴		0.1
1.500 to 1.800	10 ⁻³ to 10	1.0	
1.500 to 1.800	10 to 3 × 10 ⁴		0.1
1.800 to 10 ³	10 ⁻³ to 10	0.56 <i>t</i> ^{0.25}	
1.800 to 10 ³	10 to 3 × 10 ⁴		0.1
NOTE 1—See table 7 for correction factors <i>C</i> _A and <i>C</i> _C			
NOTE 2—For extended sources in the retinal hazard region (0.4 μm to 1.400 μm), see Table 5b			
NOTE 3—For repeated (pulsed) exposures, see 8.2.3.			
NOTE 4—The wavelength region λ ₁ to λ ₂ means λ ₁ ≤ λ < λ ₂ .			
NOTE 5—The exposure duration <i>t</i> ₁ to <i>t</i> ₂ means <i>t</i> ₁ ≤ <i>t</i> ≤ <i>t</i> ₂ .			

**Table 5b – Maximum Permissible Exposure (MPE) for
Extended-source Ocular Exposure to an OCS Laser Beam**

Wavelength (μm)	Exposure Duration, t (s)	MPE	
		($\text{J}\cdot\text{cm}^2$)	($\text{W}\cdot\text{cm}^2$)
Visible			
0.600 to 0.700	10^{-3} to T_2	$1.8\ C_E\ t^{0.75} \times 10^{-3}$	
0.600 to 0.700	T_2 to 3×10^4		$1.8\ C_E\ T_2^{-0.25} \times 10^{-3}$
Near Infrared			
0.700 to 1050	10^{-3} to T_2	$1.8\ C_A\ C_E\ t^{0.75} \times 10^{-3}$	
0.700 to 1050	T_2 to 3×10^4		$1.8\ C_A C_E\ T_2^{-0.25} \times 10^{-3}$
1.050 to 1.400	10^{-3} to T_2	$9.0\ C_C\ C_E\ t^{0.75} \times 10^{-3}$	
1.050 to 1.400	T_2 to 3×10^4		$9.0\ C_C\ C_E\ T_2^{-0.25} \times 10^{-3}$
NOTE 1—See Table 7 and Figures 1, 2 and 3 for correction factors C_A , C_C and C_E and time T_2 .			
NOTE 2—The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$.			
NOTE 3—The exposure duration t_1 to t_2 means $t_1 \leq t \leq t_2$.			
NOTE 4—See Tables 4a, 4b and 4c for limiting apertures.			
NOTE 5—For sources subtending an angle greater than 11 mrad, the MPEs may also be expressed as an integrated radiance.			
NOTE 6—Table 5a can be used as a default as the MPE values listed are worst-case. Table 5b provides relaxed MPE values associated with the effects of extended-source viewing.			

**Table 6 – Maximum Permissible Exposure (MPE)
for Skin Exposure to an OCS Laser Beam**

Wavelength (μm)	Exposure duration (s)	MPE	
		(J·cm ²)	(W·cm ²)
Visible and near infrared			
0.600 to 1.400	10 ⁻³ to 10	1.1 C _A t ^{0.25}	
0.600 to 1.400	10 to 3 × 10 ⁴		0.2 C _A
Far infrared			
1.400 to 1.500	10 ⁻³ to 10	0.56 t ^{0.25}	
1.400 to 1.500	10 to 3 × 10 ⁴		0.1
1.500 to 1.800	10 ⁻³ to 10	1.0	
1.500 to 1.800	10 to 3 × 10 ⁴		0.1
1.800 to 2.600	10 ⁻³ to 10	0.56 t ^{0.25}	
1.800 to 2.600	10 to 3 × 10 ⁴		0.1
2.600 to 10 ³	10 ⁻³ to 10	0.56 t ^{0.25}	
2.600 to 10 ³	10 to 3 × 10 ⁴		0.1
NOTE 1—See Table 7 for correction factor C _A .			
NOTE 2—The wavelength region λ ₁ to λ ₂ means λ ₁ ≤ λ ≤ λ ₂ .			
NOTE 3—The exposure duration t ₁ to t ₂ means t ₁ ≤ t ≤ t ₂ .			

Table 7 – Parameters and Correction Factors

Parameters/correction factors	Wavelength (μm)	Explanation	Applicable figure
$C_A = 1.0$	0.600 to 0.700	Correction factor to increase AELs and MPEs between 0.700 and 1.400 to account for reduced absorption of energy at the retina.	Figure 1
$C_A = 10^{2(\lambda - 0.700)}$	0.700 to 1.050		
$C_A = 5.0$	1.050 to 1.400		
$C_C = 1.0$	1.050 to 1.150	Correction factor to increase AELs and MPEs between 1.150 and 1.400 to account for pre-retinal absorption.	Figure 2
$C_C = 10^{18(\lambda - 1.150)}$	1.150 to 1.200		
$C_C = 8$	1.200 to 1.400		
$C_E = 1.0 \quad \alpha < \alpha_{\min}$	0.600 to 1.400	Correction factor to increase AELs and MPEs associated with larger retinal image sizes.	
$C_E = \alpha / \alpha_{\min} \quad \alpha_{\min} \leq \alpha \leq \alpha_{\max}$	0.600 to 1.400		
$C_E = \alpha^2 / (\alpha_{\max} + \alpha_{\min}) \quad \alpha > \alpha_{\max}$			
$T_2 = 10 \times 10^{(\alpha - 1.5) / 98.5}$	0.600 to 1.400	T_2 accounts for the reduced impact of small eye movements in spreading retinal energy for larger image sizes.	Figure 3
NOTE 1—Wavelengths must be expressed in μm and angles in milliradians for calculations.			
NOTE 2—The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda \leq \lambda_2$.			
NOTE 3—For wavelengths between 0.600 μm and 1.400 μm , $\alpha_{\min} = 1.5$ mrad, $\alpha_{\max} = 100$ mrad.			
NOTE 4— $T_2 = 10$ s for $\alpha < 1.5$ mrad, and $T_2 = 100$ s for $\alpha > 100$ mrad.			
NOTE 5—These correction factors, which are based on ANSI Z136.1-2007, may change (consult the latest revision of ANSI Z136.1).			

Table 8a – Output Power Limits for Hazard Levels (OFCS)
(Average Power Emitted from Unterminated Optical Fiber in W)

Hazard Level						
Wave-length (m)	1 Distance=25 mm Time=10 s	1M Distance=100 mm Time=10 s	2 Distance=25 mm Time=0.25 s	2M Distance=100 mm Time=0.25 s	3R Distance=25 mm Time=10 s	3B Distance=25 mm Time=10s
0.600 to 0.700	$3.9 \times 10^{-4} C_E k$	$3.9 \times 10^{-4} C_E k$	$10^{-3} C_C k$	$10^{-3} C_C k$	$5.0 \times 10^{-4} C_E k$	$0.5 k$
0.700 to 1.050	$3.9 \times 10^{-4} C_A C_E k$	$3.9 \times 10^{-4} C_A C_E k$	—	—	$2.0 \times 10^{-3} C_A C_E k$	$0.5 k$
1.050 to 1.400	$2.0 \times 10^{-3} C_C C_E k$	$2.0 \times 10^{-3} C_C C_E k$	—	—	$10.1 \times 10^{-3} C_C C_E k$	$0.5 k$
1.400 to 1.500	$1.0 \times 10^{-2} k$	$1.0 \times 10^{-2} k$	—	—	$5.0 \times 10^{-2} k$	$0.5 k$
1.500 to 4.000	$1.0 \times 10^{-2} k$	$1.0 \times 10^{-2} k$	—	—	$5.0 \times 10^{-2} k$	$0.5 k$
NOTE—See Table 7 for correction factors and Table 8b for k values.						

Table 8b – Parameters used in Table 8a

Parameter	Multi-mode Optical Fiber	Single-mode Optical Fiber
k = inverse of aperture efficiency ^{a, b}	$k = \left[1 - e^{\left(\frac{d_0}{D_L} \right)^2} \right]^{-1}$	$k = \left[1 - e^{\left(\frac{d_0}{D_L} \right)^2} \right]^{-1}$
D_L = beamwidth at measurement distance l	$D_L = \frac{2 l NA}{1.7}$	$D_L = \frac{2 l \lambda}{\pi \omega_0}$ typical optical fiber beam profile $D_L = \frac{2 \sqrt{2} l \lambda}{\pi \omega_0}$ Gaussian beam profile
d_0 = limiting aperture diameter	(Table 4b)	(Table 4b)

^a Aperture efficiency is the ratio of the energy transmitted through an aperture of specified diameter and distance from the output of an optical fiber to the total amount of energy in the beam.

^b See Figure 8a and Figure 8b for graphical presentation of k for multi-mode and single-mode optical fibers, respectively.

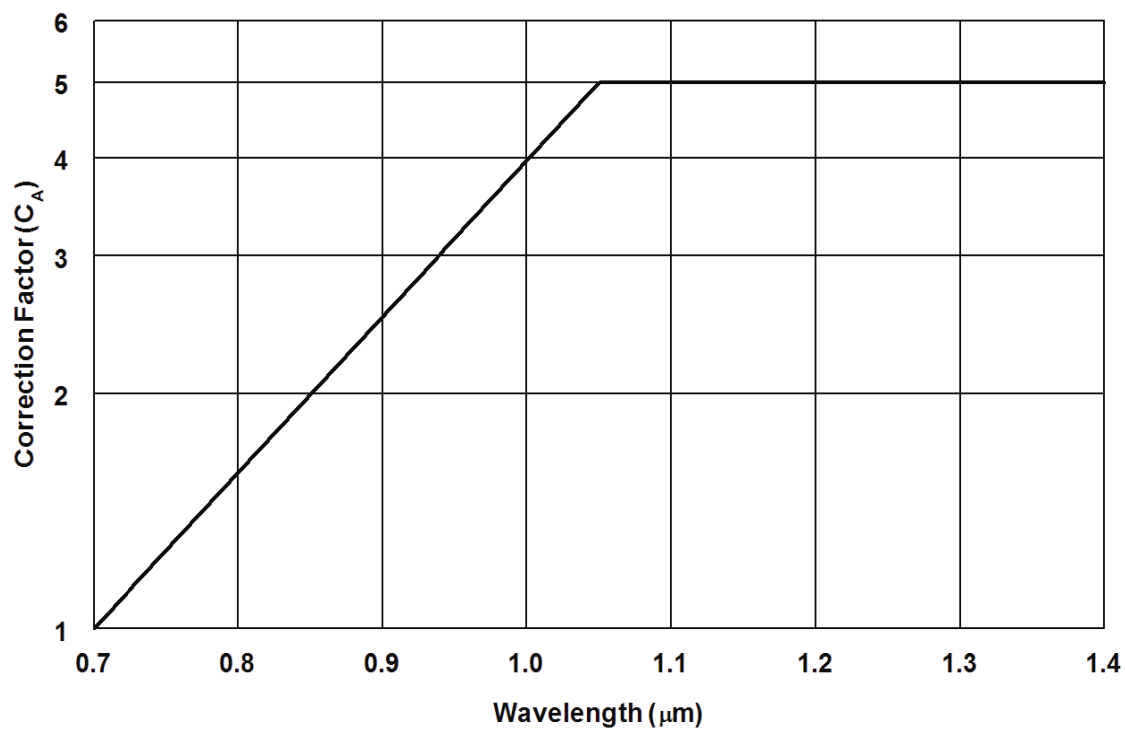
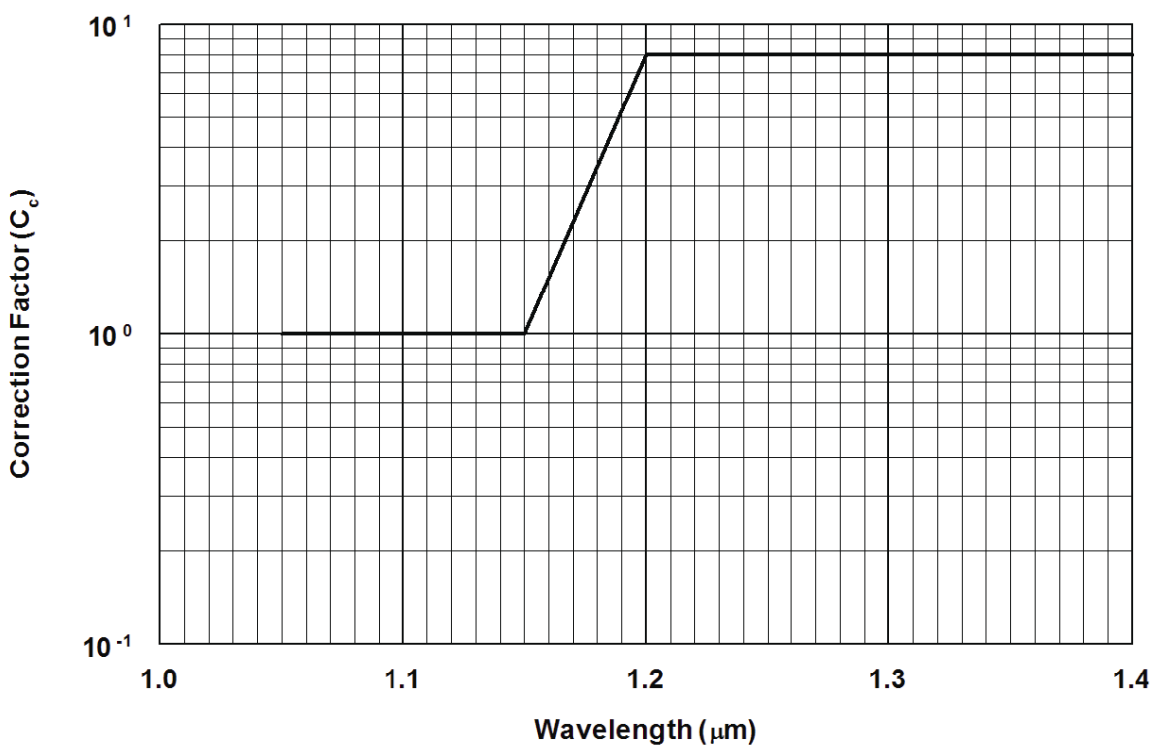


Figure 1 – Correction factor C_A used to Determine the MPE for Wavelengths Between 0.700 μm and 1.400 μm

NOTE— $C_A = 1$ for $\lambda = 0.600 \mu\text{m}$ to $0.700 \mu\text{m}$; $C_A = 10^{2(\lambda - 0.700)}$ for $\lambda = 0.700 \mu\text{m}$ to $1.050 \mu\text{m}$; $C_A = 5$ for $\lambda = 1.050 \mu\text{m}$ to $1.400 \mu\text{m}$.



**Figure 2 – Correction Factor C_c used to Determine the MPE
for Wavelengths Between 1.050 μm and 1.400 μm**

NOTE— $C_c = 1.0$ for $\lambda = 1.050$ μm to 1.150 μm ; $C_c = 10^{18(\lambda - 1.150)}$ for $\lambda = 1.150$ μm to 1.200 μm ; $C_c = 8$ for $\lambda = 1.200$ μm to 1.400 μm

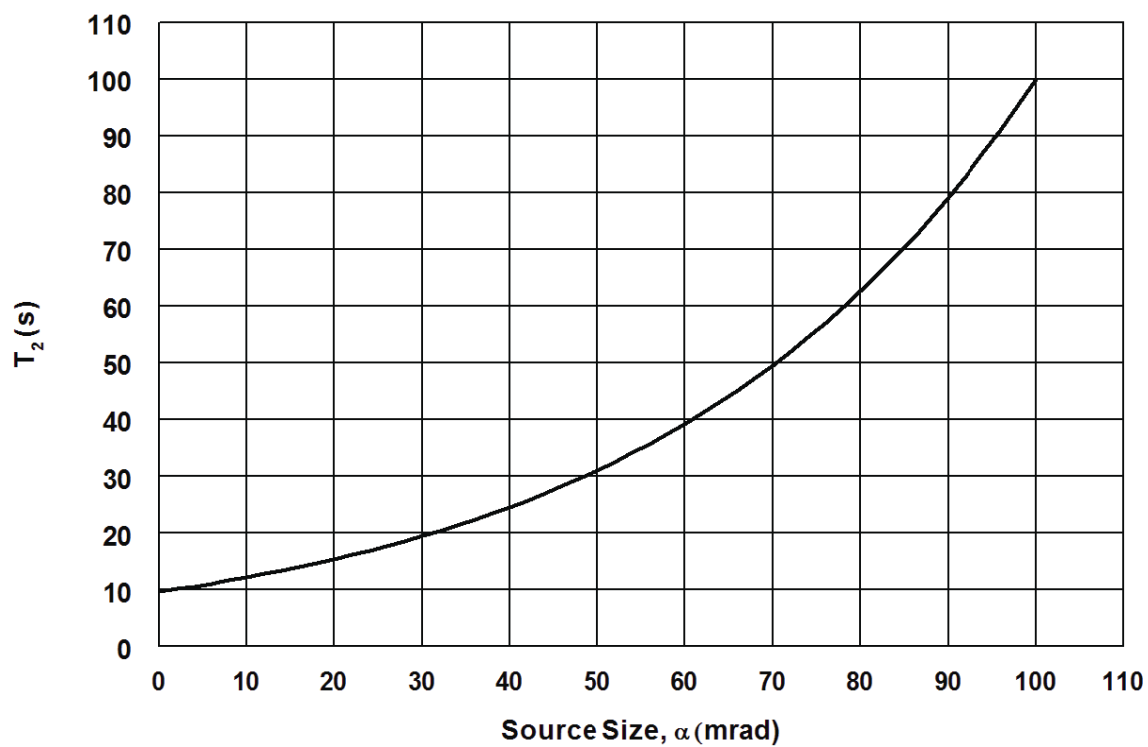


Figure 3 – Correction factor T_2 used to Determine the Extended-source MPE Based on Thermal Effects for Exposure Durations Greater than T_2 (See Table 7)

NOTE— $T_2 = 10 \times 10^{(\alpha - 1.5)/98.5}$ for wavelengths between 0.400 and 1.400 μm (α is in mrad)

$T_2 = 10$ s for point sources

$T_2 = 100$ s for sources equal to or exceeding 100 mrad

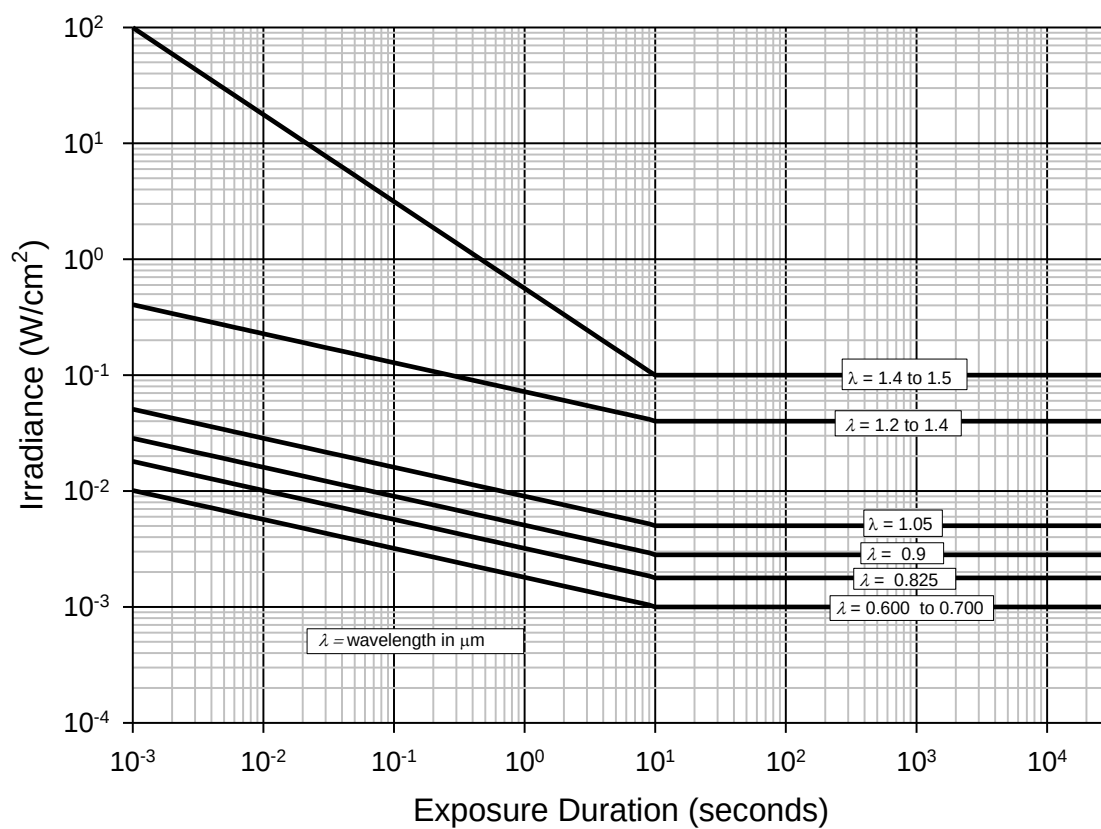


Figure 4 – Ocular MPE for Point-source Viewing for Wavelengths Between $0.600\ \mu\text{m}$ and $1.4\ \mu\text{m}$. All Values are Multiplied by the Correction Factor C_E (Equals Unity for Point Sources). See Table 7 for the Value of C_E for Extended (Large) Sources.

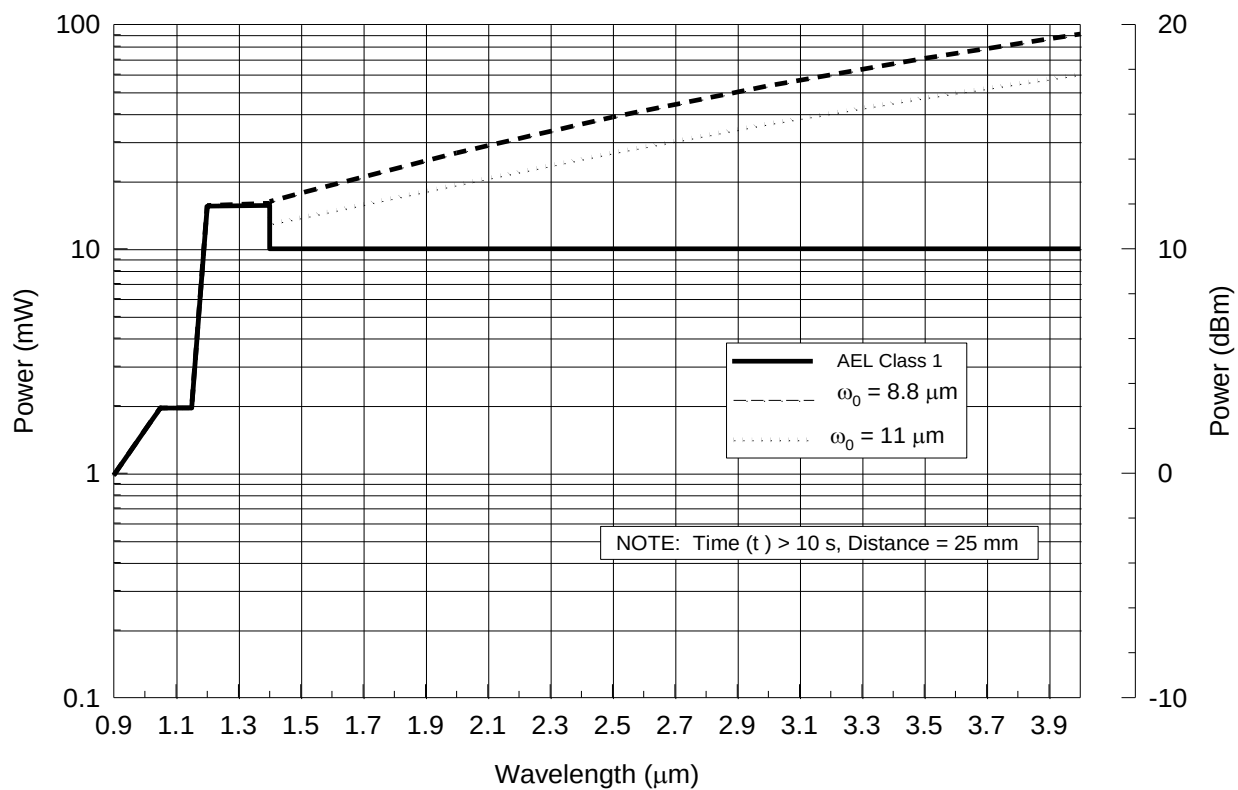


Figure 5a – Hazard Level 1 AEL – Single-mode Optical Fiber

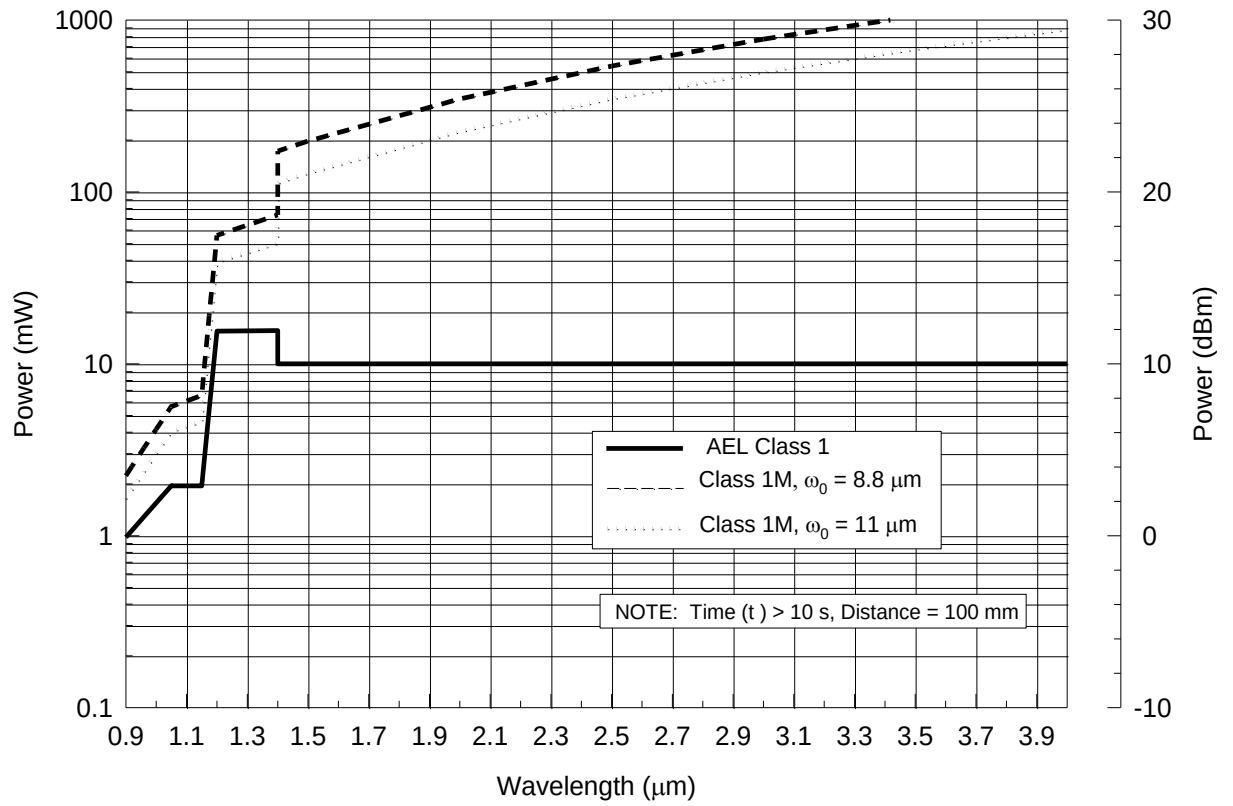


Figure 5b – Hazard Level 1M AEL – Single-mode Optical Fiber

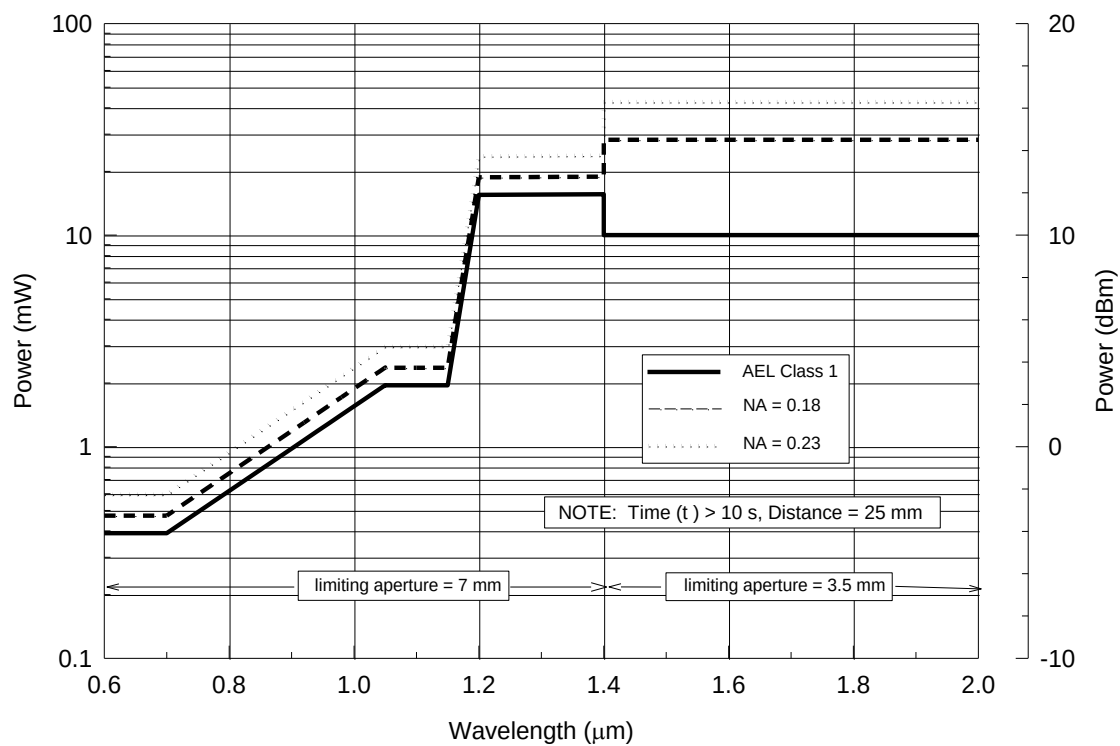


Figure 5c – Hazard Level 1 AEL – Multi-mode Optical Fiber (10X Eye-loupe)

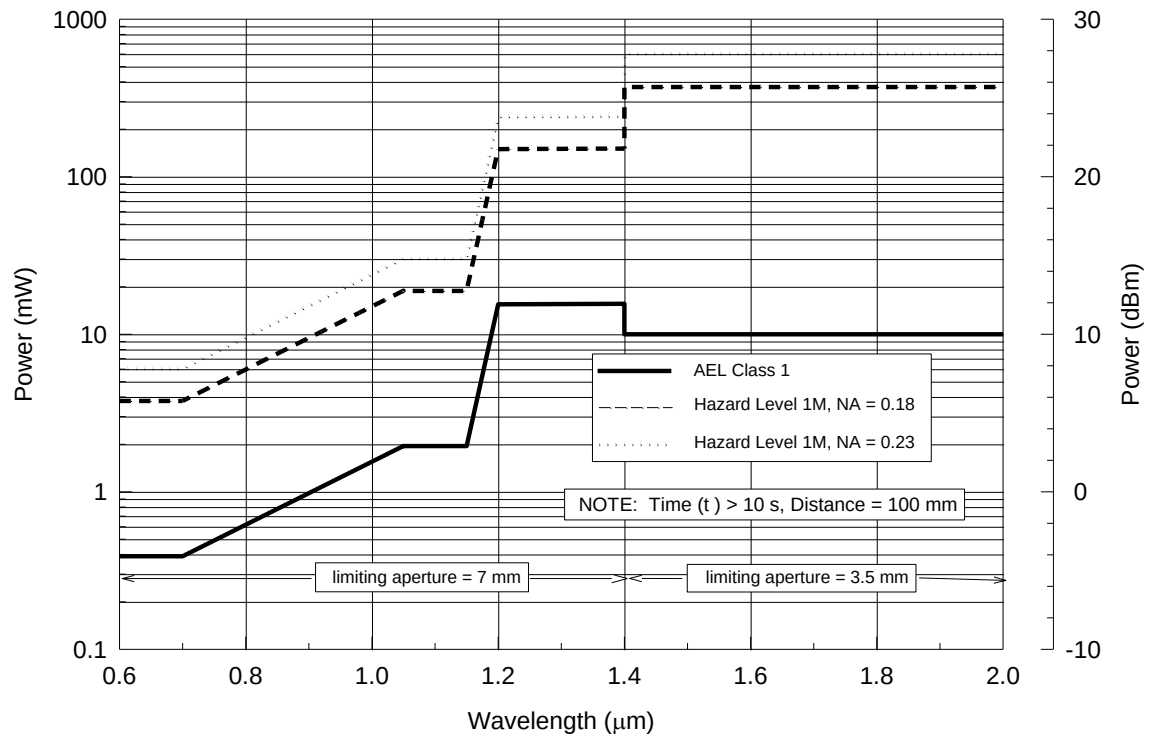


Figure 5d – Hazard Level 1M AEL – Multi-mode Optical Fiber (Unaided Eye)

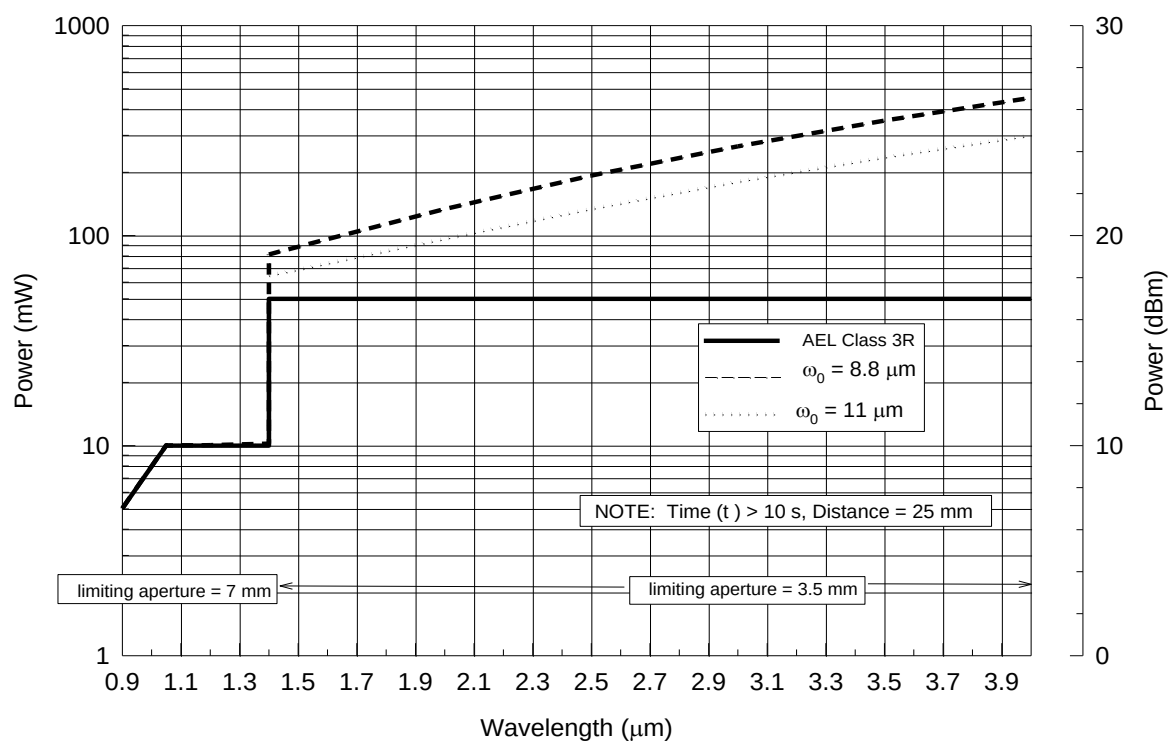


Figure 6a – Hazard Level 3R AEL – Single-mode Optical Fiber

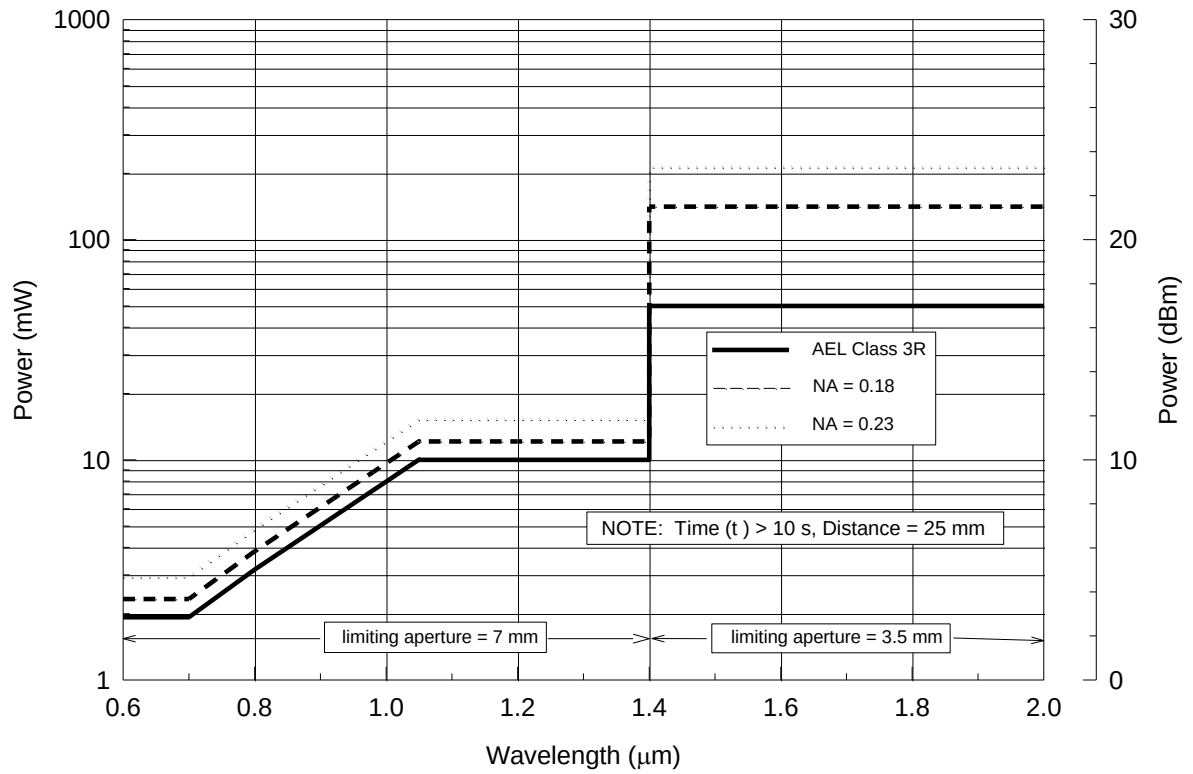


Figure 6b – Hazard Level 3R AEL –Multi-mode Optical Fiber

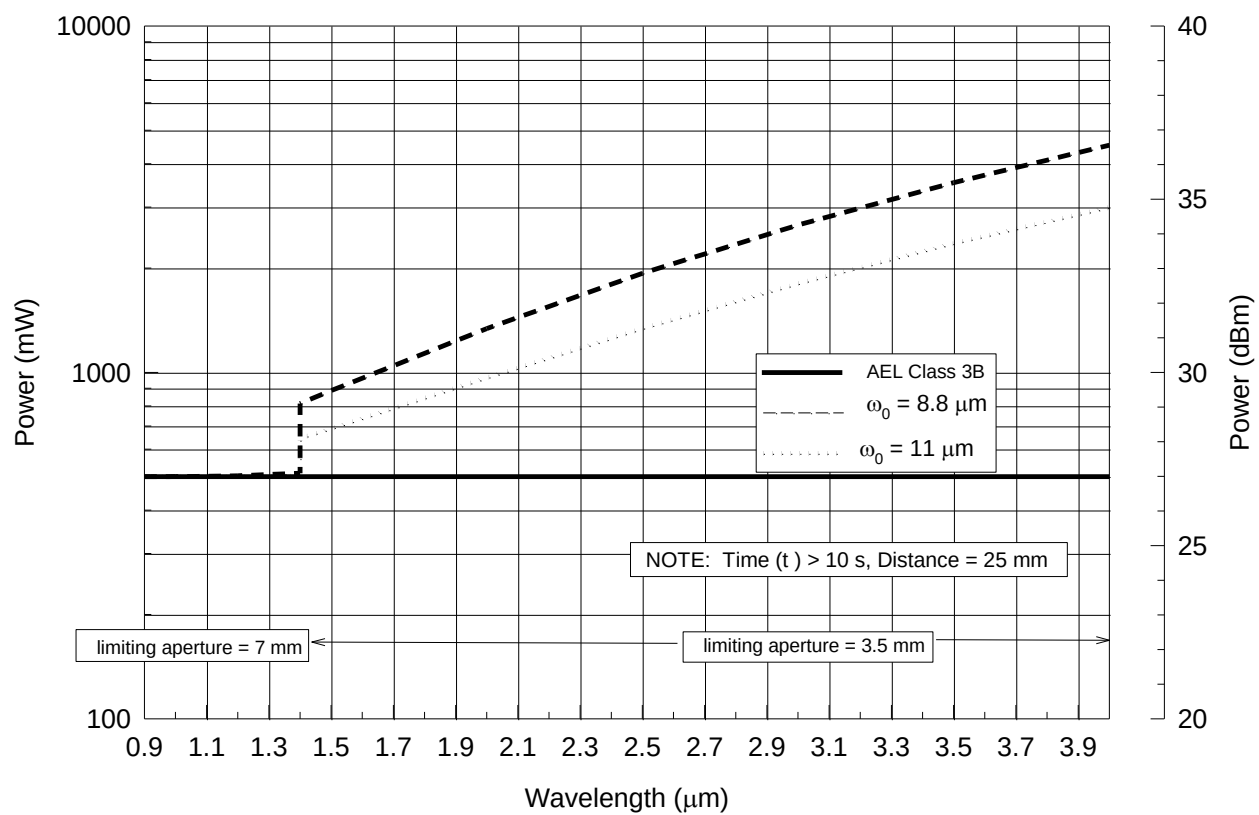


Figure 7a – Hazard Level 3B AEL – Single-mode Optical Fiber

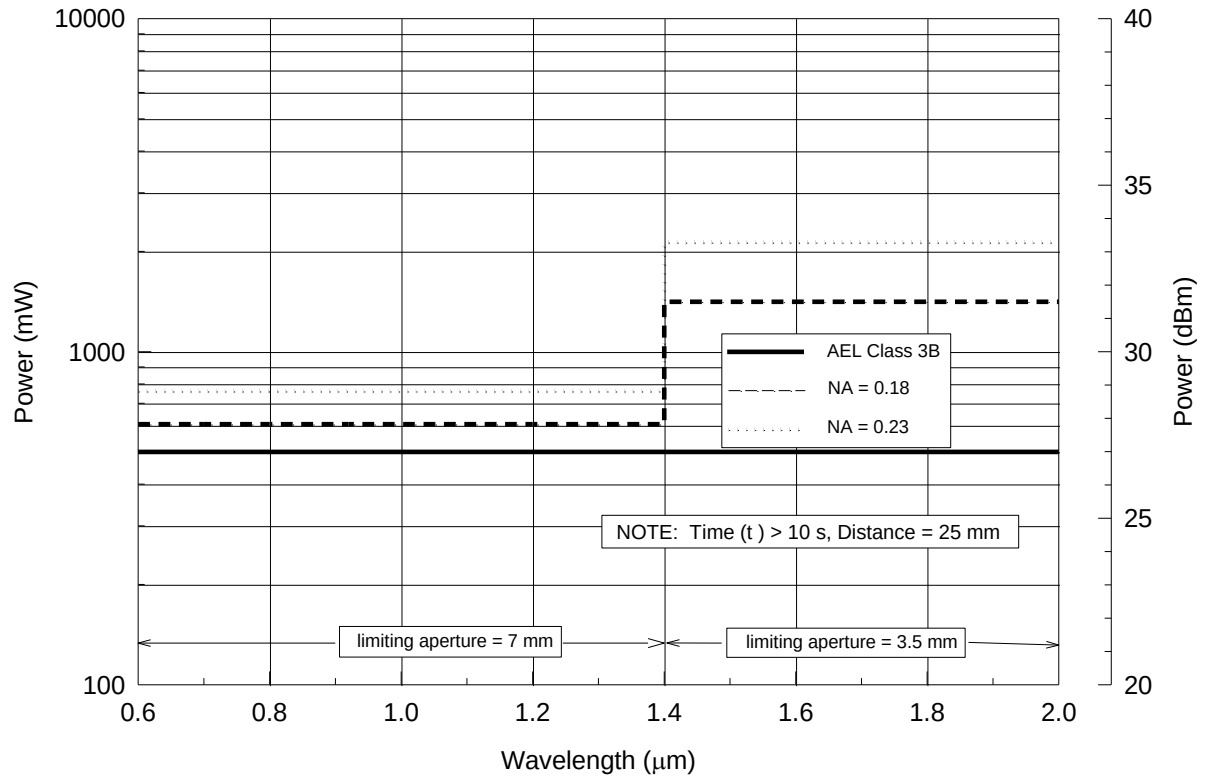


Figure 7b – Hazard Level 3B AEL – Multi-mode Optical Fiber

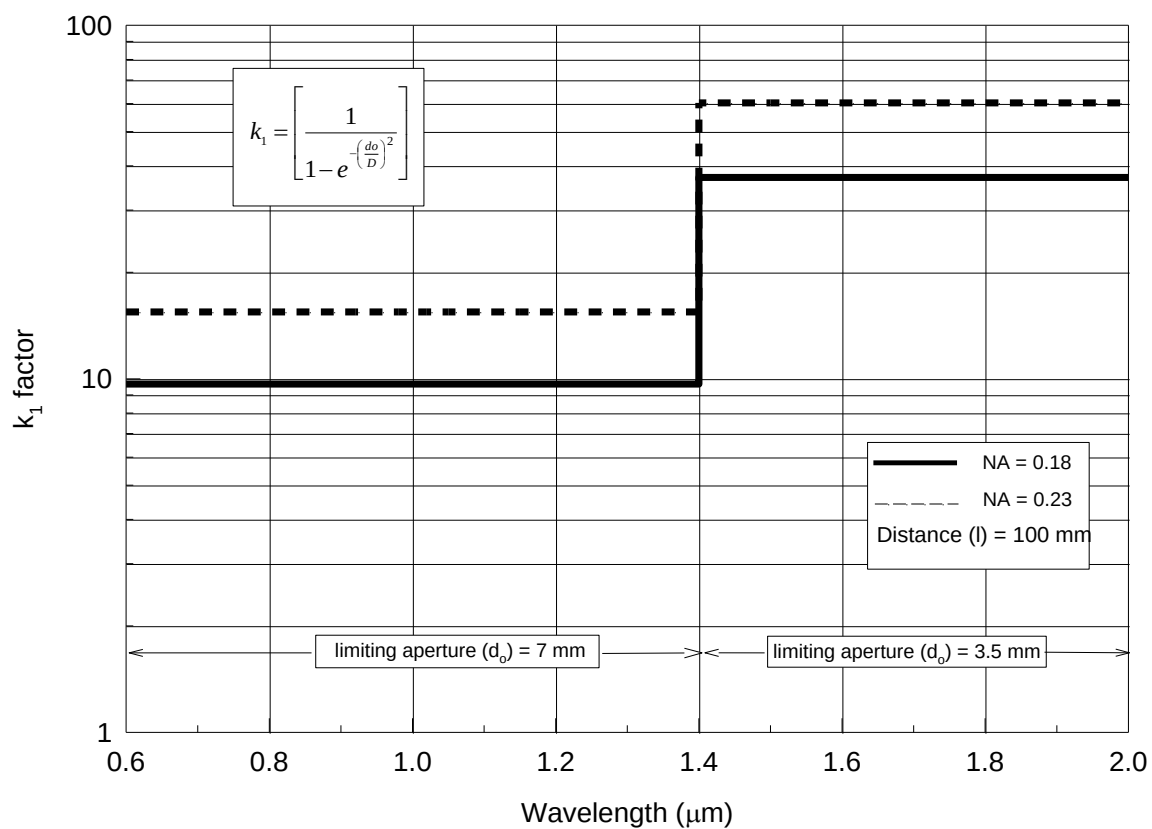


Figure 8a – Graphical Representation of k , i.e., the Reciprocal of the Aperture Efficiency, at a Distance of 100 mm for Selected Multi-mode Optical Fibers

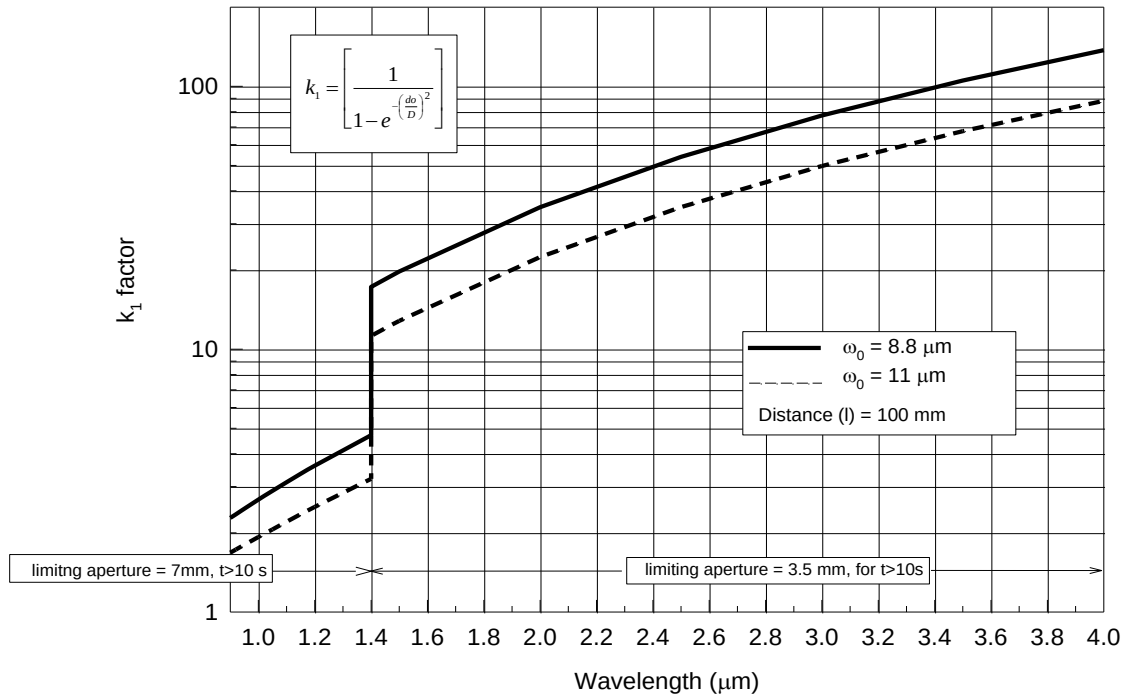


Figure 8b – Graphical Representation of k , i.e., the Reciprocal of the Aperture Efficiency, at a Distance of 100 mm for Selected Single-mode Optical Fibers

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Appendix A

Examples of Typical Viewing Conditions, Nominal Ocular Hazard Distances (NOHD), and AELs for OFCS Hazard Levels

A.1 General

Although the hazard level and access level classification defines the appropriate control measures required for an OFCS and FSOCS, respectively, there are situations where additional information is useful. To assist in obtaining this information, several figures are provided. Figures A.1 and A.2 are schematic representations of unaided and optically-aided viewing, respectively, for purposes of determining the NOHD. Figure A.3 is a schematic representation of the measurement setup for determining the OFCS hazard level.

Figure A.4 is a schematic representation of a measurement setup for determining the OFCS hazard level when the laser source is extended and C_E is applied. Note that in Figure A.4, the emitted power from the source that falls outside the acceptance angle γ ($\alpha > \alpha_{\max}$) is excluded from the measurement; therefore, the maximum value of C_E that should be applied to the hazard level is that computed for $\alpha = \alpha_{\max}$.

When $\alpha < \alpha_{\max}$, then determination of the angular subtense of the source is necessary and the measurement setup illustrated in Figure A.4 can be modified by either substituting a CCD array or a screen for the detector, which can then be examined by using a separate camera focused on the screen. Careful lens selection and placement is necessary to ensure that an image is formed at the desired location. Note that the measurement of α is only valid if the measurement distance in Figure A.4 can be maintained when bringing the image to focus. In addition, measurement is required to ensure that the observed image contains a preponderance of the emitted power and not an artifact.

Figures A.5 through A.7 show the NOHDs, as a function of optical power, for several different single-mode and multi-mode optical fibers commonly used for OFCS.

The AELs for the OFCS hazard levels are discussed in Section 3 and are shown in Table 8. For convenience, the AELs are plotted for Hazard Levels 1 through 3B in Figures A.5 thru A.7 for standard optical fibers and commonly-used wavelengths.

Examples of calculations required for determining the MPE, OFCS hazard level, FSOCS access level, NOHD, etc. are presented in Appendix B.

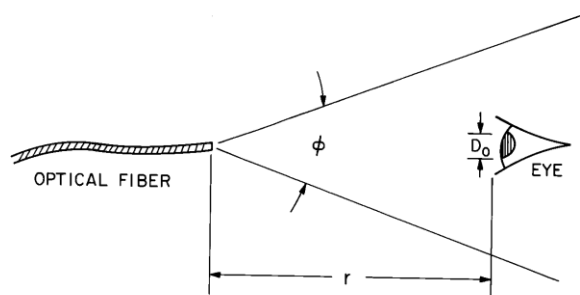


Figure A.1 – Unaided Viewing

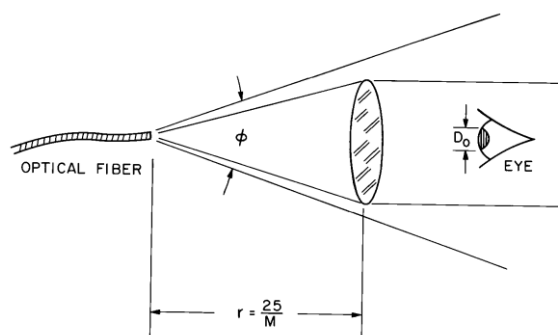
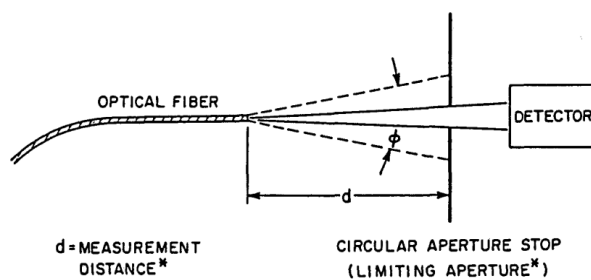
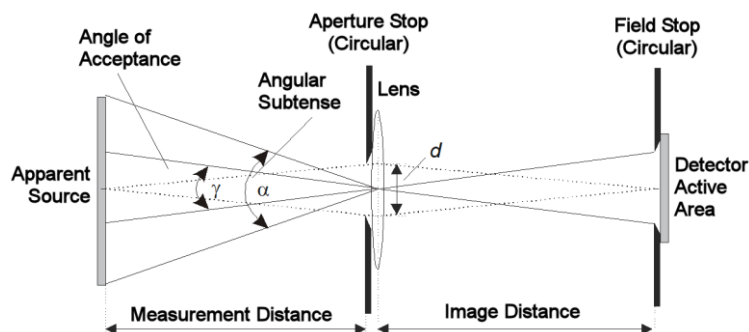


Figure A.2 – Optically Aided Viewing



* SEE TABLE 2

Figure A.3 – Measurement Arrangement used for Determining OFCS Hazard Level



**Figure A.4 – Measurement Arrangement used to Determine the OFCS Hazard Level.
(For cases where α must be measured to determine C_E for calculating the limit.)**

NOTE—The aperture stop diameter d is used to define the acceptance angle γ . If the image of the apparent source at the image distance fills the field stop, then $\alpha > \alpha_{\max}$ and only radiant power within $\alpha_{\max}$ is collected for determining the hazard level (applicable C_E is based on $\alpha_{\max}$ and not on α). If the image size s at the image distance (adjusted to produce a sharp image of the source) is clearly within the field stop (typical), $\alpha = s / (\text{image distance})$.

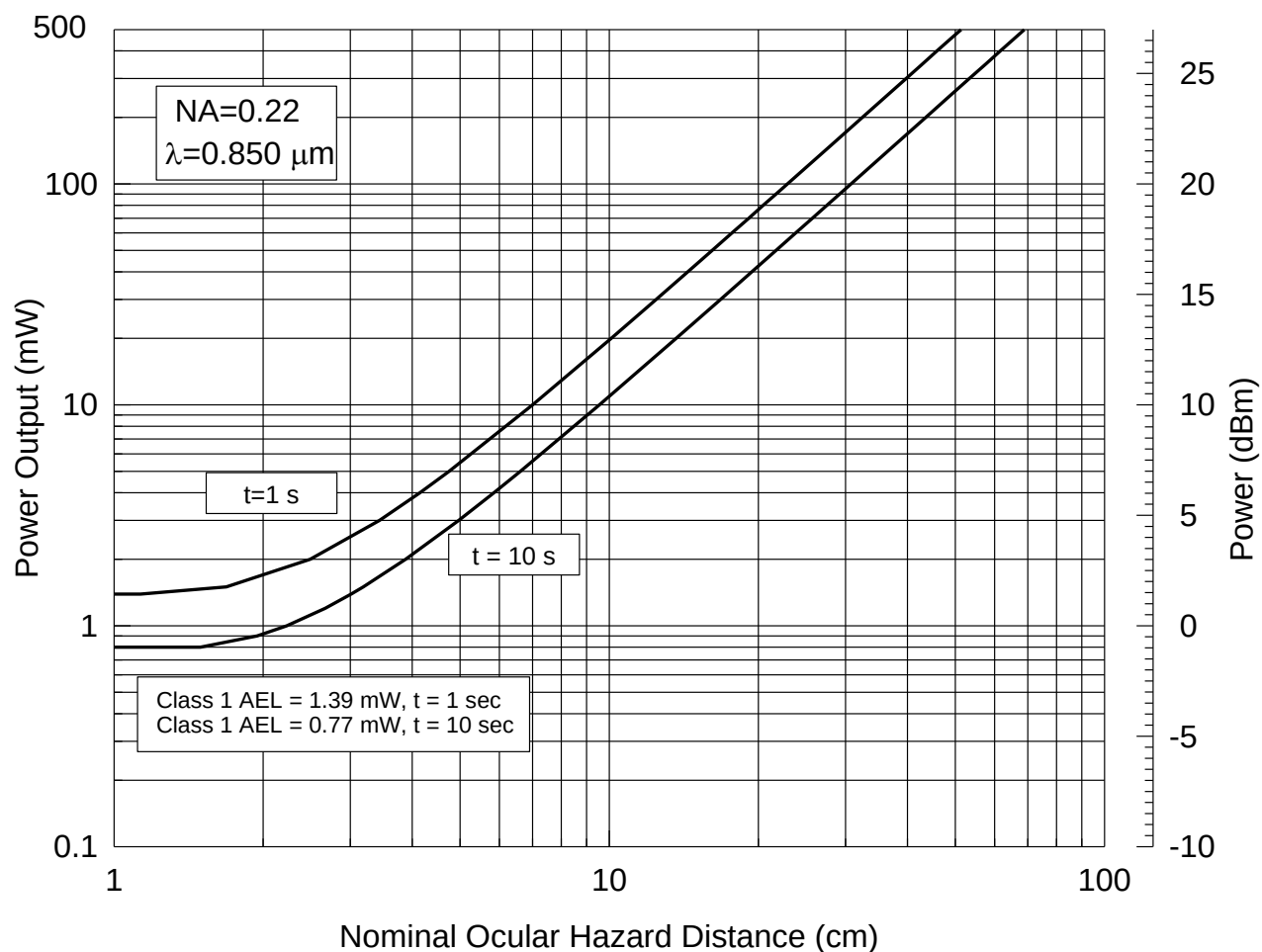


Figure A.5 – Nominal Ocular Hazard Distance as a Function of Output Power for a Multi-mode Optical Fiber with a Numerical Aperture of 0.22 Operating at 0.850 μm .

NOTE—Figures A.5, A.6 and A.7 are based on the following equation, which incorporates the aperture efficiency (η):

$$r_{NOHD} = \frac{\pi \omega_o d_o}{2\lambda} \left[\frac{-1}{\ln \left[1 - \frac{\pi d_o^2 (MPE)}{4 \times \Phi_o} \right]} \right]^{1/2}$$

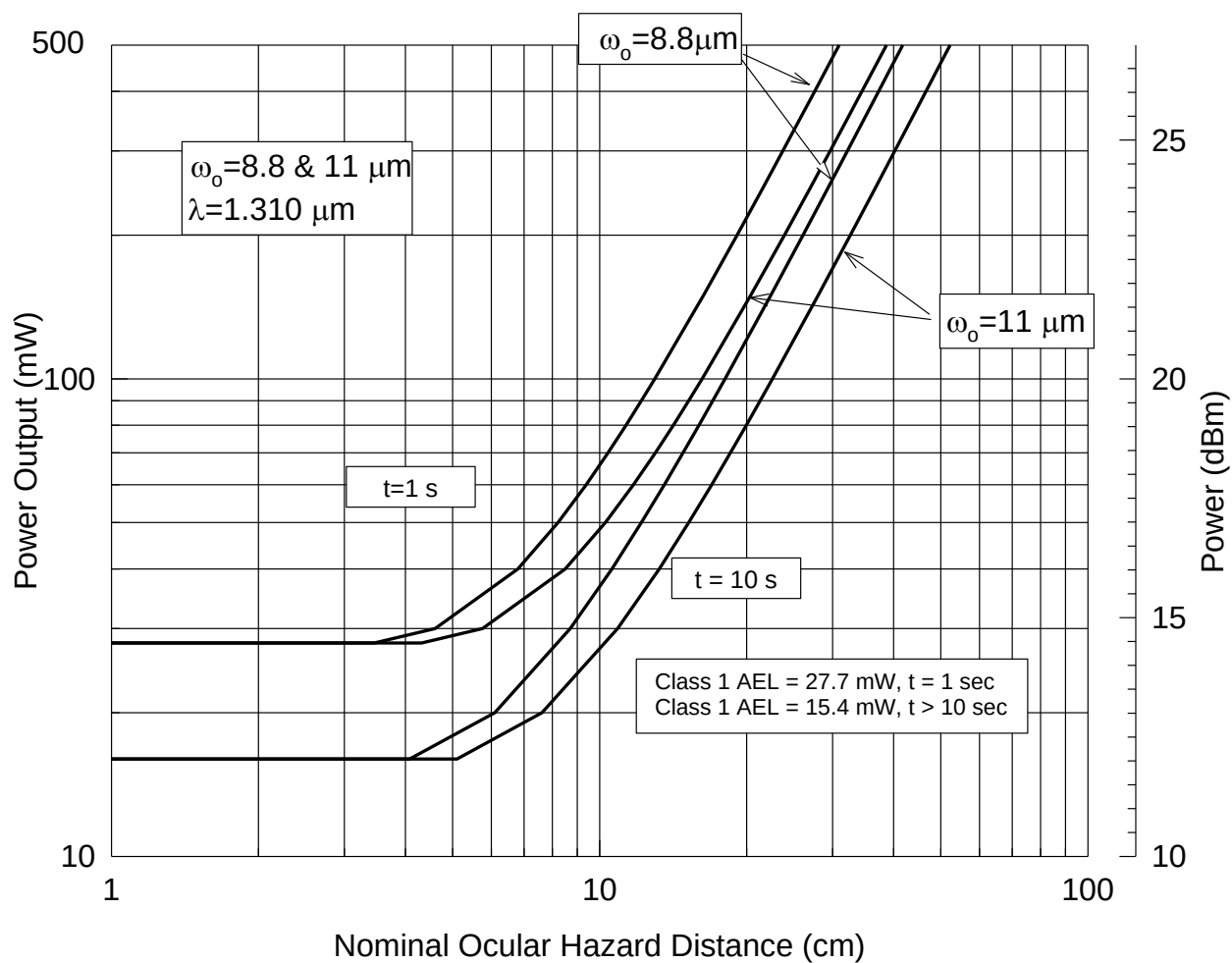


Figure A.6 – Nominal Ocular Hazard Distance as a Function of Output Power for a Single-mode Optical Fiber with a Mode-field Diameter (ω_0) Equal to 8.8 μm and 11 μm Operating at 1.310 μm .

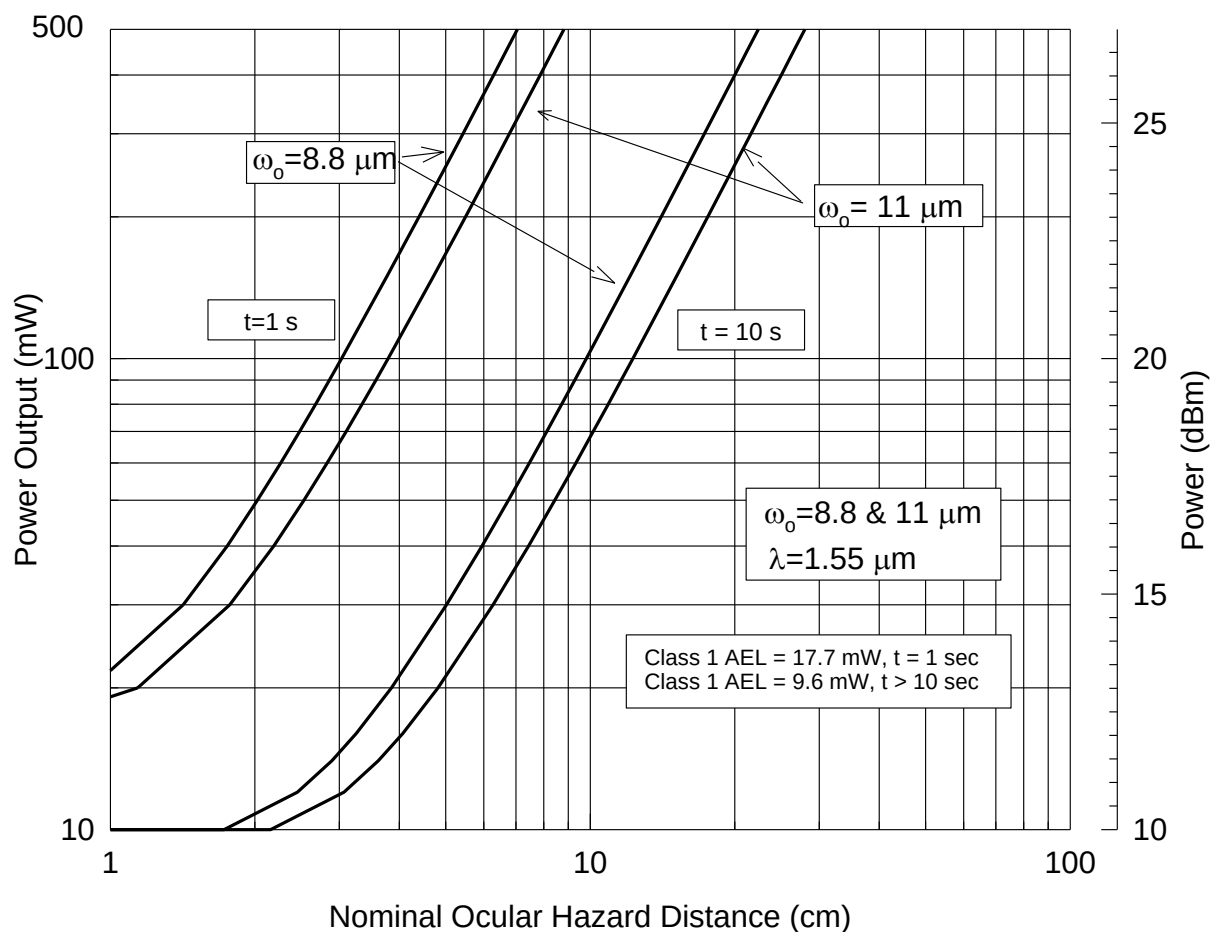


Figure A.7 – Nominal Ocular Hazard Distance as a Function of Output Power for a Single-mode Optical Fiber with a Mode-field Diameter (ω_0) Equal to 8.8 μm and 11 μm Operating at 1.55 μm .

Table A.1 – Typical Optical Fibers used in Telecommunications Applications

Diameter^a (μm)	Nominal Mode Field/Core Diameter (μm)	Numerical Aperture	Typical Wavelength Range (μm)	Application (Typical)
9/125	8.8 – 11	14 – 16	1.26 – 1.36 and 1.53 – 1.57	Telephony
50/125	50	20 – 23	0.825 – 0.980	Data
62.5/125	62.5	27 – 29	0.825 – 0.980	Data

^a Core diameter/fiber diameter

Appendix B

Examples of Applications and Calculations

B.1 General

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

Mathematical symbols used in this appendix are defined in B.2. Hazard level and access level classification and MPE determination may require the use of formulas in B.3. Figures A.1 and A.2 in Appendix A show two conditions of ocular exposure associated with OFCS. Figures A.5 through A.7 graphically illustrate the nominal ocular hazard distance (NOHD) for several types of commonly used single-mode and multimode optical fibers used in the telecommunications industry.

B.2 Symbols

The following symbols are used in the formulas of this appendix:

a = Diameter of emergent laser beam (cm).

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

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

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

C_A = Wavelength correction factor ($0.700 \mu\text{m} < \lambda < 1.050 \mu\text{m}$).

C_C = Wavelength correction factor ($1.150 \mu\text{m} < \lambda < 1.400 \mu\text{m}$).

C_E = Extended-source correction factor ($= \alpha/\alpha_{\min}$ for source angles less than 100 mrad).

C_p = Repetitive-pulse correction factor ($= n^{-0.25}$).⁹

d_e = Diameter of the pupil of the eye (varies from appropriately 0.2 to 0.7 cm).

d_0 = Diameter of limiting or measurement aperture.

D_L = Diameter of laser beam at distance l (cm).

D_λ = Optical density at a particular wavelength (λ).

D_w = Diameter of a beam waist which occurs in front of the laser exit port (cm).

e = Base of natural logarithms (2.71828).

⁹ For pulse repetition frequencies less than the critical frequency.

f = Effective focal length of the eye (1.7 cm).

f_0 = Focal length of a lens (cm).

F = Pulse-repetition frequency, PRF (s^{-1}).

F_{eff} = Effective (average) PRF (s^{-1}).

G = Ratio of corneal irradiance or radiant exposure through magnifying optics to that received by the unaided eye.

G_f = Effective gain of an optical device.

η = Aperture efficiency.

H, E = Radiant exposure (H) or irradiance (E) at range l , measured in $J \cdot cm^{-2}$ for pulsed lasers and $W \cdot cm^{-2}$ for CW lasers, respectively.

H_0, E_0 = Emergent beam radiant exposure (H_0) or irradiance (E_0) at the minimum measurement distance (10 cm) (units as for E, H).

H_{group} = Radiant exposure for the summation of all the energies in a group of pulses.

λ = Wavelength of source (μm).

l = Distance from end of optical fiber when calculating beam diameter and aperture efficiency (cm).

L_e = Radiance of an extended source ($W \cdot cm^{-2} \cdot sr^{-1}$).

L_p = Integrated radiance of an extended source ($J \cdot cm^{-2} \cdot sr^{-1}$).

MPE = Maximum permissible exposure.

$MPE:E$ = MPE expressed as irradiance. For exposure to single pulses, the MPE is for peak power, and for a group of pulses, the MPE is for the average power ($W \cdot cm^{-2}$).

$MPE:H_{\text{group}}$ = MPE expressed as radiant exposure for the summation of all the energy in a group of pulses ($J \cdot cm^{-2}$).

$MPE:H$ = MPE expressed as radiant exposure for a single pulse or exposure ($J \cdot cm^{-2}$).

$MPE/Pulse$ = MPE expressed as radiant exposure for each pulse in a pulse train ($J \cdot cm^{-2}$).

MPE_{skin} = MPE for skin exposure.

NA = Numerical aperture of optical fiber. For emission from an optical fiber, the numerical aperture is the half-angle beam divergence measured at $1/e^3$ of peak irradiance.

n = refractive index.

P = Magnifying power of an optical instrument.

ϕ = Emergent beam divergence measured at the $1/e$ peak of irradiance points (rad).

ϕ_1 = Emergent beam divergence of the major cross-sectional dimension of a rectangular or elliptical beam (rad).

ϕ_2 = Emergent beam divergence of the minor cross-sectional dimension of a rectangular or elliptical beam (rad).

ϕ = Radiant power (W).

ϕ_0 = Total radiant power output of a CW laser, or average radiant power of a repetitive-pulse laser (W).

ϕ_d = Radiant power transmitted by an aperture (W).

ϕ_{eff} = Power transmitted by a measurement aperture (W).

Q = Radiant energy (J).

Q_0 = Total radiant energy output of a pulsed laser (J).

r_{NHZ} = Nominal hazard zone.

r_{NOHD} = The distance along the axis of the unobstructed beam from the laser beyond which the irradiance or radiant exposure is not expected to exceed the appropriate MPE (cm).

r_0 = Distance from exit port to a beam waist formed in front of the laser (cm).

ρ_λ = Spectral reflectance of a diffuse or specular object at wavelength λ .

t = Duration of single pulse or exposure (s).

τ_λ = Transmission of an optical device, including windows, at wavelength λ .

T = Total exposure duration (in seconds) of a train of pulses.

T_2 = Exposure duration beyond which the thermal MPE for an extended source is constant in terms of irradiance.

T_{max} = Total expected exposure duration (see 8.2.2).

θ_v = Viewing angle from the normal to a reflecting surface; (see Fig. B4).

ω_0 = Mode field diameter of a single-mode optical fiber (μm). Note that the mode field diameter is similar to the beam waist radius at $1/e^2$ peak of irradiance points (also designated ω_0) discussed in many optics text books, but is twice the value.

B.3 Examples of MPE Determination and Hazard Level Determination (OFCS)

B.3.1 Determining the MPE. The MPEs are given in Tables 5 thru 7. Examples 1-3 are for OFCS operating at pulse repetition frequencies (PRF) greater than 55 kHz ($0.6 \mu\text{m} \leq \lambda < 1.05 \mu\text{m}$) and 22 kHz ($1.05 \mu\text{m} \leq \lambda < 1.4 \mu\text{m}$). Example 4 refers to a laser with a pulse-duration less than those frequencies and a pulse width less than 1 ms; therefore, the MPE for this example must be obtained from ANSI Z136.1.

B.3.1.1 Single Exposures

Example 1: Determine the MPE for direct intrabeam exposure to the emission from a single-mode fiber (point source viewing conditions) for a 10 s duration at $0.825 \mu\text{m}$.

Solution. The MPE from Table 5a is given by

$$MPE = 1.8 C_A t^{0.75} \times 10^{-3} \text{ J} \cdot \text{cm}^{-2} \quad 10^{-3} < t \leq 10 \text{ s},$$

and,

$$MPE = C_A \times 10^{-3} \text{ W} \cdot \text{cm}^{-2} \quad t \geq 10 \text{ s}$$

where C_A (from Table 7) is given by,

$$C_A = 10^{2(\lambda - 0.700)} \quad 0.700 \text{ } \mu\text{m} \leq \lambda < 1.050 \text{ } \mu\text{m}.$$

Thus,

$$C_A = 10^{2(0.825 - 0.700)} = 10^{0.25} = 1.78,$$

and

$$MPE = 1.78 \times 10^{-3} \text{ W} \cdot \text{cm}^{-2}.$$

Example 2: Determine the MPE for direct exposure to a 1.525 μm OFCS or FSOCS. Assume that the maximum exposure duration is 5 s.

Solution. The MPE in terms of radiant exposure from Table 5a is,

$$MPE: H = 1.0 \text{ J} \cdot \text{cm}^{-2}.$$

MPE: E is found by dividing the radiant exposure by the exposure duration,

$$MPE: E = \frac{MPE: H}{t} = \frac{1.0}{5} = 0.2 \text{ W} \cdot \text{cm}^{-2}.$$

Example 3: A 0.632 μm HeNe laser is coupled into an optical fiber and used as a fault locator. Determine the MPE for an inadvertent exposure under point source viewing conditions.

Solution. Since the laser operates in the visible region, the appropriate exposure duration is 0.25 s. The MPE from Table 5a is,

$$MPE: H = 1.8 t^{0.75} \times 10^{-3} \text{ J} \cdot \text{cm}^{-2},$$

or, by dividing by t ,

$$MPE: E = 1.8 t^{-0.25} \times 10^{-3} \text{ W} \cdot \text{cm}^{-2}.$$

Substituting the values from the example into the above equation yields,

$$MPE: E = 1.8 (0.25)^{-0.25} \times 10^{-3} = 2.55 \times 10^{-3} \text{ W} \cdot \text{cm}^{-2} = 2.55 \text{ mW} \cdot \text{cm}^{-2}.$$

B.3.1.2 Multiple Exposures. Some test sets, e.g., some optical time domain reflectometers, may operate at PRFs less than 55 kHz ($0.6 \text{ } \mu\text{m} \leq \lambda < 1.05 \text{ } \mu\text{m}$) or 22 kHz ($1.05 \text{ } \mu\text{m} \leq \lambda < 1.4 \text{ } \mu\text{m}$), in which case the MPE for a single pulse and the number of pulses, n , during the exposure duration must be determined (see 8.2.3). The MPE for each of the pulses during the exposure duration is the product of $n^{-0.25}$ and the MPE for a single pulse. The “cumulative” MPE

for the exposure duration is equal to the product of the corrected MPE/pulse and the number of pulses in the exposure.

Example 4: An optical time domain reflectometer (OTDR) is used for locating a fault in an optical fiber. The OTDR operates at 0.825 μm at a PRF of 10 Hz. Determine the MPE for a direct exposure of 10 s under point source viewing conditions. The pulse width is 1 μs.

Solution. Since MPEs are not provided for pulse durations less than 1 ms in this standard, the MPE for a single, 1 μs pulse, as given in Table 5a of Z136.1-2007, is

$$\begin{aligned} MPE : H &= 0.5 C_A \times 10^{-6} \text{ J} \cdot \text{cm}^{-2} \\ &= 0.5 \times 10^{2(\lambda - 0.700)} \times 10^{-6} \text{ J} \cdot \text{cm}^{-2}. \end{aligned}$$

Substituting the value from the example into the above equation yields,

$$\begin{aligned} MPE : H &= 0.5 \times 10^{2(0.825 - 0.700)} \times 10^{-6} \\ &= 0.5 \times 10^{2(0.125)} \times 10^{-6} \\ &= 8.9 \times 10^{-7} \text{ J} \cdot \text{cm}^{-2}. \end{aligned}$$

The number of pulses n occurring in exposure duration T (10 s) is,

$$n = T \times \text{PRF} = 10 \times 10 = 10^2.$$

The MPE per pulse is,

$$\begin{aligned} MPE/\text{pulse} : H &= (n)^{-0.25} \times MPE : H \text{ J} \cdot \text{cm}^{-2} \\ &= (10^2)^{-0.25} \times 8.9 \times 10^{-7} \\ &= 2.8 \times 10^{-7} \text{ J} \cdot \text{cm}^{-2}. \end{aligned}$$

The cumulative MPE for the entire pulse train is the MPE/pulse times the number of pulses in the train (or group), or,

$$\begin{aligned} MPE : H_{\text{group}} &= n \times MPE/\text{pulse} \text{ J} \cdot \text{cm}^{-2} \\ &= 10^2 \times 2.8 \times 10^{-7} = 2.8 \times 10^{-5} \text{ J} \cdot \text{cm}^{-2}. \end{aligned}$$

This may also be expressed in terms of average irradiance,

$$\begin{aligned} MPE : E &= \frac{H}{t} = \frac{2.8 \times 10^{-5} \text{ J} \cdot \text{cm}^{-2}}{10 \text{ s}} = 2.8 \times 10^{-6} \text{ W} \cdot \text{cm}^{-2} \\ &= 2.8 \text{ } \mu\text{W} \cdot \text{cm}^{-2}. \end{aligned}$$

B.3.2 Determining the Hazards. The AELs for OFCS Hazard Levels 1 through 3B are shown in Table 1 through Table 3 and are plotted for selected parameters in Figures 5 through 7. In order to determine the hazard level of a specific OFCS, the amount of optical power that is transmitted through a specified limiting aperture located at a specified distance must be measured or calculated for a specified exposure duration (see Table 4a and Table 4b for limiting apertures and Figure A3 for the physical arrangement). In order to calculate the above value, it is necessary to determine the beam diameter at the measurement distance. From the knowledge of the beam

diameter and aperture diameter, the percentage of the power transmitted through the aperture, and central beam irradiance can be determined.

B.3.2.1 Determining the Central Beam Irradiance. The beam diameter of the radiation emitted from an optical fiber is highly variable with the distance from the end of the fiber. The beam expands rapidly with the divergence defined by the numerical aperture (NA) for multi-mode fibers and by the mode field diameter for single-mode fibers. The central beam irradiance of a Gaussian beam of diameter D (defined at the 1/e-of-peak-irradiance points) is given by

$$E = \frac{\Phi_0}{\left(\frac{\pi}{4}\right)D^2} = \frac{4\Phi_0}{\pi D^2} \text{ W}\cdot\text{cm}^{-2}, \quad (\text{B1})$$

where Φ_0 is the average output power. Equation B1 also provides reasonable values for the central beam irradiance from non-Gaussian beams when the beam diameter used in the equation is defined at the 1/e of peak irradiance points.

B.3.2.2 Determining the Beam Diameter and Divergence for Multi-mode Fibers as Described by the NA. The NA of an optical fiber is defined as the sine of one-half of the divergence, ϕ' , of the output beam, as measured at the 5%-of-peak-irradiance points. That is,

$$NA = \sin \frac{\phi'}{2}$$

and

$$\frac{\phi'}{2} = \sin^{-1}(NA)$$

The beam diameter, D_L , at a distance l from the end of the fiber is given by

$$D_L' = a + 2l \tan \frac{\phi'}{2} \approx a + 2l \tan \left[\sin^{-1}(NA) \right]$$

Since a is of the order of a few tens of μm , it can be ignored and

$$D_L' \approx 2l \tan \left[\sin^{-1}(NA) \right] \approx 2 \times l \times NA$$

NOTE—These formulas are accurate only for small divergence angles; the accuracy is better than 1% for angles less than 0.17 rad (10°) and better than 5% for angles less than 0.37 rad (21°).

It is assumed that the cross-section profile of the output beam is Gaussian (a conservative assumption) and, hence, the value of D' must be converted to reflect the beam diameter D at the 1/e-of-peak-irradiance points. The correction factor is 1.7 and, hence,

$$D_L = \frac{D_L'}{1.7} = \frac{2 \times l \times NA}{1.7} \text{ cm} \quad (\text{B2})$$

$$\phi = \frac{2 \times NA}{1.7} \text{ rad.} \quad (\text{B3})$$

Example 5: The output beam diameter, a' , of a lens connector measured at the $1/e^2$ of the peak-irradiance points is 1.5 mm. The NA of the system is 0.003. Determine the beam diameter at 50 cm.

Solution. Substituting the values in the above equation gives:

$$D' = 0.15 + (2 \times 50) \tan[\sin^{-1}(0.003)] = 0.45 \text{ cm.}$$

Applying the correction factor for D_L (defined at $1/e$ points) used in safety calculations,

$$D_L = \frac{D'}{1.7} = \frac{0.45}{1.7} = 0.26 \text{ cm} = 2.6 \text{ mm.}$$

Example 6: An OFCS utilizing a multi-mode fiber with a numerical aperture (NA) of 0.22 operates at $1.33 \mu\text{m}$ at a power level of 1.2 mW (0.8 dBm). Determine the beam diameter and central beam irradiance at a distance of 7 cm.

Solution. Substituting the values from the example into Equation B2 yields,

$$D_L = \frac{2 \times l \times NA}{1.7} = \frac{2 \times 7 \text{ cm} \times 0.22}{1.7} = 1.81 \text{ cm.}$$

Hence, for this example, the central beam irradiance at 7 cm from the fiber tip from Equation B1 is,

$$E = \frac{4\Phi_0}{\pi D_{\text{mm}}^2} = \frac{4 \times 1.2 \times 10^{-3} \text{ W}}{\pi (1.81 \text{ cm})^2} = 0.46 \text{ mW} \cdot \text{cm}^{-2}.$$

B.3.2.3 Determining the Beam Diameter and Divergence for Single-mode Fibers as Described by the Mode Field Diameter. Note that the fiber core diameter would be smaller than the mode field diameter; for this example, the core could vary from less than $1 \mu\text{m}$ to about $8.4 \mu\text{m}$, depending on the composition of the fiber.^{10,11} The far field divergence (θ_{FF}) of a Gaussian beam, defined as the angle describing the beam profile between the peak irradiance in the center of the beam, and the location where the local irradiance is $1/e^2$ of that at the center of the beam is:¹²

$$\theta_{\text{FF}} = \frac{\lambda}{\pi \omega_0},$$

¹⁰ R. Paschotta, RP Photonics, Virtual Library, Encyclopedia of Laser Physics and Technology, Mode radius (2007).

¹¹ D. Marcuse, Loss analysis of single-mode fiber splices, Bell Syst. Tech. J. 56, 703 (1977).

¹² W.J. Marshall, Determining hazard distances from non-Gaussian lasers, Applied Optics, 30(6), 696-698 (1991).

where ω_0 is the beam radius at the beam waist, which is defined as the distance between the beam center and the radial location where the local irradiance is $1/e^2$ of that at the center.

The beam divergence used for laser safety is the full angle of the beam cross section, where the local irradiance is $1/e$ of that at the center of the beam. For a true Gaussian shape, $\phi = \sqrt{2} \theta_{FF}$. For fiber optics, the mode field diameter is defined as twice the beam radius (unfortunately the same symbol is used to represent the mode field diameter as has been used in other optics texts to represent the beam radius). Therefore,

$$\phi = \sqrt{2} \times \theta_{FF} = \frac{2\sqrt{2}\lambda}{\pi\omega_0},$$

where ω_0 now represents the mode field diameter for a fiber optic system.

Although the above equation has been determined from basic theory for a Gaussian profile beam, the emission from most fibers is not Gaussian and the profiles often appear either as a tophat or have a parabolic profile. The actual results of beam profile measurements of the emission patterns from optical fibers indicate that a different equation is more indicative of the actual beam pattern, and produces conservative results for hazard evaluation and for determining hazard level. The use of the following equation precludes the use of measured values to verify calculations,

$$\phi = \frac{2\lambda}{\pi\omega_0}. \quad (B4)$$

NOTE—Equation B4 produces more conservative results (smaller beamwidth) than the Gaussian beam equation and has been found to closely match the observed beam patterns. Therefore, Equation B4 will be used for single-mode fiber calculations included in this Appendix.¹³

Assuming Gaussian propagation, the beam diameter, D_L , at a distance l from the end of the fiber is given by,

$$D_L = \sqrt{D_w^2 + (l\phi)^2},$$

where D_w is the exit beam diameter (beam waist), defined at $1/e$ of peak of irradiance points at the end of the fiber. Note that the small angle approximation is used in this equation also; however, if the angles involved are less than 0.17 rad, the accuracy is within 1 %. Since D_w is almost always much less than the second term for distances of interest, it may be ignored,

$$D_L = l\phi. \quad (B5)$$

¹³ Extensive measurements at the National Institute of Standards and Technology (NIST) during the 1980s showed repeatedly that peak irradiance calculations based on Equation B4 best describe the corresponding measured values for single-mode optical fibers. While many texts with theoretical derivations of the beam divergence give a broader beamwidth, particularly if the known core diameter is substituted for the mode field diameter, experimental work demonstrated that the core diameter is not the mode field diameter. Thus for calculations in this standard, the formulas based on Equation B4 are used throughout Appendix B, and may be somewhat conservative in some instances, but will never understate the potential exposure.

Example 7: Assume that the optical fiber for *Example 6*, for a 1.2 mW output at 1.33 μm , is single-mode with a mode field diameter, ω_0 , of 9.2 μm . Determine the beam diameter and the central beam irradiance at a distance of 7 cm.

Solution. The divergence of the beam is based on the mode field diameter of 9.2 μm ,

$$\phi = \frac{2 \times (1.33 \mu\text{m})}{\pi \times (9.2 \mu\text{m})} = 0.092 \text{ radians.}$$

Substituting the values from the example we get:

$$D_L = l\phi = (7 \text{ cm})(0.092) = 0.64 \text{ cm.}$$

The central beam irradiance is computed by

$$E = \frac{4\Phi_0}{\pi D_L^2} = \frac{4 \times 1.2}{\pi (0.64)^2} = 3.73 \text{ mW} \cdot \text{cm}^{-2}.$$

B.3.2.4 Determining the Fraction of Power Passing Through a Specified Limiting Aperture.

In order to determine the hazard level of an OFCS, the fraction of the total power passing through a specified limiting aperture at a specified distance must be determined. The fraction of the power, η , that passes through an aperture of diameter, d_0 , at a distance, l , can be found for a Gaussian beam from,

$$\eta = \left[1 - e^{-\left(\frac{d_0}{D_L}\right)^2} \right], \quad (\text{B6})$$

where D_L is the beam diameter determined at the 1/e points at the aperture distance l . The total power through the aperture is,

$$\Phi_f = \eta \times \Phi_0 \quad (\text{B7})$$

Example 8: A multi-mode fiber with an NA of 0.22 operates at 0.825 μm at a power level of 10 mW (10 dBm). Determine the power, Φ_b , passing through a 7 mm limiting aperture located 7 cm from the end of the fiber.

Solution. As determined in Example 6 above, the beam diameter for a multi-mode fiber with a NA = 0.22 at a distance of $l = 7 \text{ cm}$ is $D_L = 1.81 \text{ cm}$. The fraction of the energy collected in a 7 mm aperture at that distance from Equation B6 is then:

$$\eta = 1 - e^{-\left(\frac{d_0}{D_L}\right)^2} = 0.139.$$

From Equation B7, the power transmitted through aperture d_0 (7 mm) is:

$$\Phi_f = 0.139 \times 10 \text{ mW} = 1.39 \text{ mW.}$$

B.3.2.5 Determining the Hazard Level. There are two conditions (Table 4c) that must be tested to determine the hazard level of the laser. Condition 1 applies at a range of 2 m through a 50 mm

aperture. Condition 2 for fiber optics is applied at 7 cm through a 7 mm aperture. Both conditions must be tested, unless it is obvious that one of the conditions will determine the hazard. Footnote “a” of Table 4c states that the dividing line between the two conditions is a divergence of 5 mrad.

Testing both measurement conditions requires that the beam diameter at the classification distances must be determined. Then, the radiant power that will be transmitted through the applicable aperture located at each measurement distance is determined and compared with the accessible emission limit.

Example 9: A single-mode OFCS operates at 1.330 μm and a power level of 10 mW (10 dBm). The mode field diameter of the fiber, ω_0 , is 8.8 μm . Determine the hazard level.

Solution. Determine the accessible emission limit for Class 1. From Table 1, this is a value of $3.9 \times 10^{-4} C_A C_C \text{ W}$. Using Table 7, we find that $C_A = 5$ and $C_C = 8$. The resultant Class 1 AEL is $1.56 \times 10^{-2} \text{ W}$, or 15.6 mW. The radiant power emitted from the fiber is 10 mW, so the device is Hazard Level 1.

Example 10: A single-mode OFCS operates at 1.330 μm and a power level of 100 mW (20 dBm). The mode field diameter of the fiber, ω_0 , is 8.8 μm . Determine the hazard level.

Solution. Substituting values into Equation B2, D_L for Condition 1 is,

$$D_L = \frac{2 \times (200\text{cm}) \times (1.33\mu\text{m})}{\pi(8.8\mu\text{m})} = 19\text{ cm}.$$

Using the same equation, D_L for Condition 2 is determined to be 0.67 cm at a distance of 7 cm.

Now determine the radiant power passing through the applicable aperture for both conditions using,

$$\Phi_d = \Phi_0 \left(1 - e^{-\frac{d_0^2}{D_L^2}} \right). \quad (\text{B8})$$

For Condition 1 this would be,

$$\Phi_d = (0.1\text{W}) \left(1 - e^{-\frac{5^2}{19^2}} \right) = 6.7 \times 10^{-3} \text{ W} = 6.7\text{ mW}.$$

Using Equation B8, the radiant power passing through a 7 mm aperture for Condition 2 is $6.6 \times 10^{-2} \text{ W}$, or 66 mW, which indicates a greater hazard than Condition 1.

An alternate method of determining which measurement condition would indicate the greater hazard is to determine the beam divergence for the fiber. Beam divergence for a single-mode fiber may be determined from Equation B4,

$$\phi = \frac{2\lambda}{\pi\omega_0} = \frac{2 \times (1.33\mu\text{m})}{\pi(8.8\mu\text{m})} = 0.096 \text{ radians} = 96 \text{ mrad}.$$

Hence, this is a high divergence beam and Condition 2 would be expected to yield the most conservative results.

The Class 1 AEL is 15.6 mW, the same as from the previous example, and the radiant power transmitted through the measurement aperture for Condition 2 is 66 mW, so this device is not Hazard Level 1. However, since the transmitted power for Condition 2 is less than 5 times the Hazard Level 1, this device is Hazard Level 3R.

B.3.2.6 Hazard Evaluation. Although the hazard level is determined at predetermined distances, often the hazards from a particular viewing condition at different distances is desired, such as the hazards to a person at a specific location from the direct or specularly reflected beam.

B.3.2.6.1 Specular Reflections

Example 11: Specular reflection from a Class 3B FSOCS. A collimated beam from a Class 3B FSOCS laser operating at 4 W with a 0.2-m diameter beam and at a wavelength of 1.15 μm is directed out of an office building window at an angle 20 degrees from the normal. The reflectance for this type of glass at this angle and laser wavelength was measured to be 0.10 (10%). Evaluate the specular reflection back into the transmitter room.

Solution. The irradiance incident on the window glass from Equation B1 is,

$$E = \frac{1.27\Phi}{D_L^2} = \frac{(1.27)(4\text{ W})}{(20\text{ cm})^2} = 12.7\text{ mW} \cdot \text{cm}^{-2}.$$

The MPE at this wavelength for continuous ($> 10\text{ s}$) viewing is $5.0\text{ mW}/\text{cm}^2$. Since the window reflectance of 10 % creates a reflection which is below the MPE ($0.10 \times 12.7\text{ mW} \cdot \text{cm}^{-2} = 1.27\text{ mW} \cdot \text{cm}^{-2}$), the irradiance of the reflected beam is below the MPE; however, a risk may exist from optically-aided viewing of the scene out the window at the same time that the laser was operated. The reflected beam would exceed the MPE if viewed using a telescopic device with an effective gain of 3.9 or more. A standard pair of 7×50 binoculars has an entrance aperture of 5.0 cm, compared with the unaided eye, which is assumed to be 0.7 cm. The effective gain is 7 ($5.0\text{ cm}/0.7\text{ cm}$), assuming no safety filter and 100% transmission. If these binoculars were to be aimed out the window along the reflected beam path at the same time that the laser was operating, the user may receive an exposure above the MPE. Needless to say, reflections from the telescope objective must also be evaluated for possible reflective hazards (secondary reflections). The transmitter is best placed very close to the window glass, or a tube may be installed between the transmitter aperture and the window glass. Reflections external to the building may also be created and must be evaluated.

B.3.2.6.2 Determining the Nominal Ocular Hazard Distance (NOHD). The NOHD is defined as the distance at which the beam irradiance averaged over a specific limiting aperture is equal to the MPE for the appropriate exposure duration. Beyond that distance, the irradiance is less than the MPE. This situation is illustrated in Figure B.1.

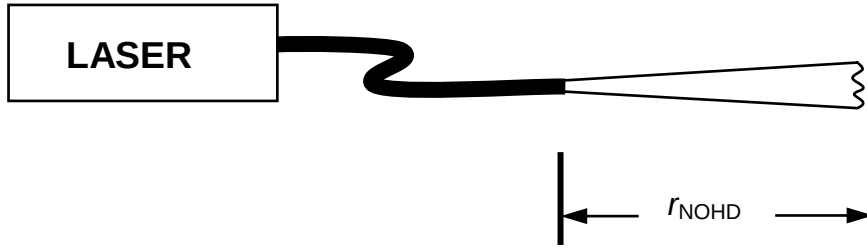


Figure B.1 Determining the NOHD (r_{NOHD}) for Emission from an Optical Fiber.

For laser energy transmitted through fiber optics, the following equations apply when determining the NOHD from the end of an open single-mode fiber,

$$r_{\text{NOHD}} = \frac{\omega_0}{\lambda} \left(\frac{\pi \Phi_0}{MPE} \right)^{1/2} \quad (\text{B9a})$$

Note that Equation B9 is different from the equation used in ANSI Z136.1-2007, but provides a conservative estimate of hazard distance for non-Gaussian beams.

Equation B9a applies when determining the NOHD from the end of an open multi-mode fiber,

$$r_{\text{NOHD}} = \frac{1.7}{NA} \left(\frac{\Phi}{\pi \times MPE} \right)^{1/2} \quad (\text{B9b})$$

Example 12: Determine the safe viewing distance for a single-mode optical fiber ($\omega_0 = 8 \mu\text{m}$) that operates at $1.330 \mu\text{m}$ at a power level of 20 mW (13 dBm). Assume an exposure duration T of 100 s.

Solution. First examine the MPEs for both skin and for point sources:

$$MPE_{\text{skin}} = 0.2 \times C_A (\text{W} \cdot \text{cm}^{-2}) \text{ and } C_A = 5.0$$

$$MPE_{\text{skin}} = 1.0 \text{ W} \cdot \text{cm}^{-2}.$$

Because $1.330 \mu\text{m}$ is within the hazard region for the eye, extended source exposure may need to be considered for some fibers but not single-mode fibers since their mode field diameter is so small. The MPE for a point source is,

$$MPE_{\text{point source}} = 5.0 \times C_C \times 10^{-3} (\text{W} \cdot \text{cm}^{-2}) \text{ and } C_C = 8.0$$

$$MPE_{\text{point source}} = 40 \times 10^{-3} \text{ W} \cdot \text{cm}^{-2}$$

To compute the NOHD, both MPEs will be considered using Equation B9a.

$$r_{\text{NOHD}} = \frac{\omega_0}{\lambda} \left(\frac{\pi \times \Phi_0}{MPE_{\text{skin}}} \right)^{1/2} = \frac{8.0 \mu\text{m}}{1.33 \mu\text{m}} \left(\frac{\pi \times 20 \times 10^{-3} \text{ W}}{1.0 \text{ W} \cdot \text{cm}^{-2}} \right)^{1/2} \approx 1.5 \text{ cm}.$$

$$r_{\text{NOHD}} = \frac{\omega_0}{\lambda} \left(\frac{\pi \times \Phi_0}{MPE_{\text{point source}}} \right)^{1/2} = \frac{8.0 \mu\text{m}}{1.33 \mu\text{m}} \left(\frac{\pi \times 20 \times 10^{-3} \text{ W}}{40 \times 10^{-3} \text{ W} \cdot \text{cm}^{-2}} \right)^{1/2} \approx 7.5 \text{ cm}.$$

Thus, there exists a hazard distance for the skin within 1.5 cm and within 7.5 cm for the eye. For retinal hazards, distances less than 7 cm are usually not considered even when magnifiers are used, so there is little retinal eye hazard.

B.3.2.6.3 Optically-aided Viewing. When an optical device such as a hand magnifier or eye-loupe is used to view the end of an optical fiber, the amount of energy that impinges on the eye is greater than the corresponding case of unaided viewing. The reason is that the optical device tends to collimate the beam (see Figure A.2) and, hence, if the end of the fiber is located at the focal distance of the lens, the effective viewing distance is reduced to that value.

Example 13: A 10× eye-loupe is used to view the end of a multi-mode optical fiber that has the following characteristics: NA = 0.22, $\Phi_0 = 1$ mW (0 dBm), wavelength (λ) = 1.330 μm . Determine whether or not the resulting exposure exceeds the applicable MPE.

Solution. First, determine the focal length (or distance to the focal point, r_{fp}) of the 10× eye loupe lens by the magnification principle. The focal length of a simple magnifier is given by,

$$r_{fp} = \frac{25\text{cm}}{\text{Magnification}} = \frac{25\text{cm}}{10} = 2.5\text{cm}. \quad (\text{B10})$$

One way to proceed is to determine the beam diameter and the corresponding value for E , as averaged over the appropriate limiting aperture (7 mm), at the plane of the lens. Then, by neglecting the losses in the lens, and assuming that the beam leaving the lens is collimated by the eye-loupe (which also has no optical losses), this value is compared with the MPE. The beam diameter, D_L at a distance, l , from the end of the fiber from Equation B2 is,

$$D_L = \frac{2l \text{ NA}}{1.7} \text{ cm},$$

where, in this case, the appropriate value of l is the focal length of the lens ($r_{fp} = 2.5$ cm).

Substituting 2.5 cm for l in Equation B11 for D_L yields,

$$D_L = \frac{2 \times 2.5\text{cm} \times 0.22}{1.7} = 0.65\text{cm}.$$

This value is smaller than the limiting aperture, and either the peak irradiance or the total power Φ_f through the appropriate limiting aperture can be used. In the case of the latter, Φ_f is found from Equation B8,

$$\Phi_f = \Phi_0 \left(1 - e^{-\left(\frac{d_0}{D_L}\right)^2} \right) \text{mW} = 1 \left(1 - e^{-\left(\frac{0.7\text{cm}}{0.65\text{cm}}\right)^2} \right) = 0.69\text{mW}.$$

The average irradiance is Φ_f divided by the area of the limiting aperture, A_0 , or

$$E = \frac{\Phi_f}{A_0} = \frac{0.69\text{mW}}{\frac{\pi}{4}(0.7\text{cm})^2} = 1.79\text{mW} \cdot \text{cm}^{-2}.$$

From Example 17, the MPE for this wavelength has been determined to be $40 \text{ mW}\cdot\text{cm}^{-2}$ for a 100 s retinal exposure duration, so the MPE is not exceeded for the 1 mW power in this example.

B.3.2.6.4 FSOCS Link Between Locations. Consider the deployment of two widely separated FSOCS terminals in a link between two restricted locations, as shown in Figure B.2.

Laser beams are emitted from both terminals with flat top profiles (constant irradiance within the beam divergence cones). Terminal A is installed in a restricted location. A building window that does not open is in front of Terminal A. At the angle that the beam is transmitted relative to the window surface, the window transmission is $\tau_w = 0.3$, and the reflectivity is $1 - \tau_w = 0.7$. The distance from Terminal A to Terminal B is the link range, $R_L = 300 \text{ m}$. Terminal B is mounted on a rooftop in a controlled location.

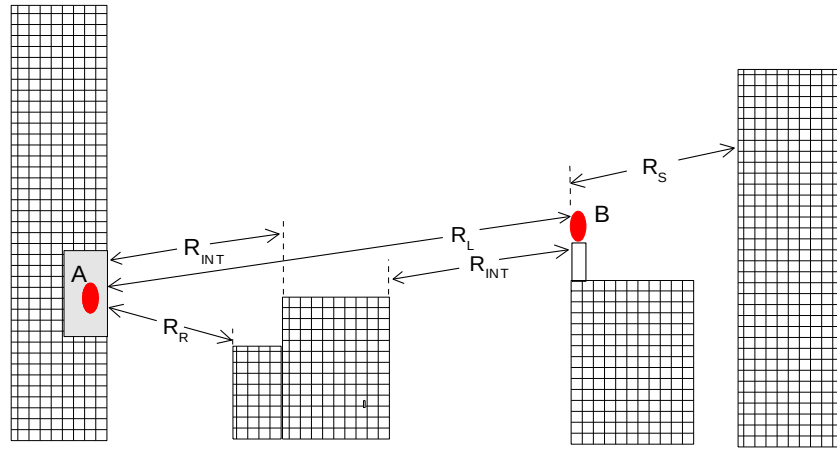


Figure B.2 FSOCS Link Between two Restricted Locations.

There are five locations to consider in this example besides the locations of the terminals:

1. The location traversed by the beam from Terminal A that partially reflects from the window in front of Terminal A.
2. The location immediately outside the window in the building where Terminal A is located.
3. The rooftop of an intermediate building located halfway between Terminal A and Terminal B. The distance to the nearest side of this building is 140 m from both Terminal A and Terminal B, represented by R_{INT} . The beam path clears this building by 2 meters vertically.
4. An unrestricted building is located at a distance $R_S = 50 \text{ m}$ beyond Terminal B and is in line to receive spillover radiation from Terminal A.

5. An unrestricted location a distance $R_R = 75$ m from Terminal A that is in line to receive radiation from Terminal B that reflects from the window just in front of Terminal A.

The characteristics of the transmitters of these terminals are as follows:

Terminal A transmitter:

Class 1M

Beam diameter at transmitter: $D_A = 100$ mm

Full axially symmetric beam divergence: $\phi_A = 2$ mrad

Wavelength: $\lambda = 1.55$ μm

Terminal B transmitter:

Class 3B

Beam diameter at transmitter: $D_B = 10$ mm

Full axially symmetric beam divergence: $\phi_B = 1$ mrad

Wavelength: $\lambda = 1.55$ μm

Example 14: Determine the maximum transmitted power for the Class 1M device located at Terminal A.

Solution. For a Class 1M device operating at 1.55 μm , the emitted beam irradiance does not exceed the MPE of $100 \text{ mW} \cdot \text{cm}^{-2}$ for unaided viewing. The exit beam diameter is 10 cm. The beam irradiance is calculated from Equation B1,

$$E = \frac{1.27\Phi}{D_A^2} = \frac{1.27\Phi_0}{(10\text{cm})^2} = 100 \text{ mW} \cdot \text{cm}^{-2}.$$

Solving for Φ_0 ,

$$\Phi_0 = \frac{(0.1 \text{ W} \cdot \text{cm}^{-2}) \times (10\text{cm})^2}{1.27} = 7.9 \text{ W},$$

to maintain the irradiance criteria for Class 1M classification.

However, the total emitted power collected within a 2.5 cm diameter aperture at 2 m cannot exceed the Class 3B criteria of 0.5 W to be classified as Class 1M.

At a distance, l , from the exit aperture, the irradiance is,

$$E = \frac{1.27\Phi_0}{(l + r\phi)^2}, \quad (\text{B11})$$

where a represents the initial beam diameter and l represents the distance from the laser exit port.

At a distance of 2 m, the irradiance as calculated from Equation B9 is,

$$E = \frac{1.27\Phi_0}{(l + r\phi)^2} = \frac{1.27(7.9 \text{ W})}{[10 \text{ cm} + (200 \text{ cm})(2 \times 10^{-3})]^2} = 92.7 \text{ mW} \cdot \text{cm}^{-2}.$$

The irradiance averaged over the measurement aperture d_0 can also be computed from,

$$E = \frac{1.27\Phi_f}{d_0^2}, \quad (\text{B12})$$

where Φ_f is the power transmitted by the measurement aperture d_0 . Therefore at 2 m,

$$E = \frac{1.27\Phi_f}{d_0^2} = \frac{1.27\Phi_f}{(2.5\text{cm})^2} = 92.7 \text{ mW} \cdot \text{cm}^{-2}$$

Solving Equation B10 for Φ_f , the power that would be collected by the measurement aperture of 2.5 cm at a distance of 2 m is,

$$\Phi_f = \frac{(92.7 \text{ mW} \cdot \text{cm}^{-2}) \times (2.5\text{cm})^2}{1.27} = 0.46 \text{ W}.$$

Therefore, a 7.9 W laser with a uniform profile, a 10 cm beam diameter, and a wavelength of 1.55 μm meets the Class 1M criteria since the transmitted power through the measurement aperture at 2 m distance does not exceed the Class 3B limit of 0.5 W. Note that the window transmission does not play a part in the classification of the product.

Example 15: Determine the maximum transmitted power for the Class 3B device located at Terminal B.

Solution. For a Class 3B device, the emitted beam can produce as much as 500 mW through the measurement aperture for unaided viewing or the use of low-power magnifiers (Condition 2) and telescopic viewing (Condition 1). So, the Class 3B limit would be the lesser of 500 mW collected within a 3.5 mm diameter aperture placed immediately in front of the transmit aperture (Condition 2) or a 25 mm diameter aperture placed 2.0 m in front of the transmit aperture (Condition 1).

Condition 2:

For the portion transmitted by the aperture, the irradiance may be calculated from Equation B10,

$$E = \frac{1.27\Phi_f}{(d_0)^2} = \frac{1.27(0.5\text{W})}{(0.35\text{cm})^2} = 5.18 \text{ W} \cdot \text{cm}^{-2},$$

where d_0 is the limiting aperture and also the measurement aperture in this case.

For the total beam power and the actual beam diameter, the irradiance is the same,

$$E = \frac{1.27\Phi_0}{(d_0)^2} = \frac{1.27\Phi_0}{(1\text{cm})^2} = 5.18 \text{ W} \cdot \text{cm}^{-2}.$$

Solving for the total beam power,

$$\Phi_0 = \frac{(5.18 \text{ W} \cdot \text{cm}^{-2}) \times (1\text{cm})^2}{1.27} = 4.08 \text{ W}.$$

Condition 1:

For the portion transmitted by the aperture, the irradiance may be calculated,

$$E = \frac{1.27\Phi_f}{(d_0)^2} = \frac{1.27(0.5\text{ W})}{(2.5\text{ cm})^2} = 10.2 \text{ W} \cdot \text{cm}^{-2}.$$

For the total beam power, the irradiance is the same,

$$E = \frac{1.27\Phi_0}{(d_0 = l + r\phi)^2} = \frac{1.27(0.5 \text{ W})}{[1 \text{ cm} + (200 \text{ cm})(0.0001)]^2} = 10.2 \text{ W} \cdot \text{cm}^{-2}.$$

$$\Phi_0 = \frac{(10.2 \text{ W} \cdot \text{cm}^{-2}) \times (1.2 \text{ cm})^2}{1.27} = 11.6 \text{ W}.$$

The lesser of these two conditions for the laser at Terminal B is a maximum total beam power of 4.08 W.

Example 16: Calculate the hazard distances of interest from the lasers located at Terminal A and Terminal B, for both unaided viewing and viewing through a typical pair of 7×50 binoculars.

Solution. By design, the laser at Terminal A is not hazardous for direct viewing, skin exposure, irradiance through the window, or for laser reflections. For telescopic viewing, however, hazards could exist for either the transmitted beam or reflected beam from the window at Terminal A. The following equation can be used to determine the hazard distance for optically aided viewing (NOHD-M),

$$NOHD - M = \frac{1}{\phi} \left(\sqrt{\frac{1.27\Phi_0\tau_w G_f}{MPE}} - l \right), \quad (\text{B13})$$

where G_f is the effective gain of the optical device being considered. Since the laser beam size is larger than the objective of the viewing optics, the effective gain is,

$$G_f = P^2 \times \tau_\lambda, \quad (\text{B14})$$

where P represents the optical power of the binoculars and τ_λ represents the expected transmission of the optical device at the laser wavelength. At 1.55 μm , the transmission of an ordinary pair of 7-power binoculars would not be expected to be greater than 70 percent. The effective gain for this example would therefore be 34.3. For direct viewing through the window, *NOHD-M* is,

$$NOHD - M = \frac{1}{(2 \times 10^{-3})} \left(\sqrt{\frac{1.27(7.9)(0.3)(34.3)}{(0.1 \text{ W} \cdot \text{cm}^{-2})}} - 10 \right) = 110 \text{ m}.$$

Thus, the hazard distances of interest are the direct and reflected NOHDs for both systems. These are as follows:

	Terminal A	Terminal B
Unaided/skin NOHD (direct)	0 m	62 m
Aided NOHD (direct)	243 m	412 m
Unaided/skin NOHD (reflected)	0 m	50 m
Aided NOHD (reflected)	195 m	343 m
Unaided/skin NOHD (transmitted)	0 m	29 m
Aided NOHD (transmitted)	110 m	221 m

Example 17: Assess the optical hazards from the laser at Terminal A at the five locations of interest, assuming the laser emits the maximum output power that meets the Class 1M limit.

Solution:

1. Terminal A: Since this is a restricted location, personnel in the area would be trained to know not to use optical aids in the area while the laser could be energized, so no further controls are necessary on the basis of the reflections from the window at Terminal A.
2. Terminal B: The direct aided hazard distance from the laser that is pointed in the direction of Terminal B is less than the separation distance from Terminal A to Terminal B, so no further controls are necessary.
3. Outside the window at Terminal A: Here, the likelihood of window cleaning personnel having and using optical aids must be considered to determine control measures. As it would typically be considered unlikely that people in this location would have optical aids, it is likely that no further control measures would be necessary. An LSO might require a sign visible to window-cleaning personnel notifying them of the possibility of a hazard when using optical aids.
4. Neighboring building: The rooftop of an intermediate building is located $R_1 = 140$ m from Terminal A, which is beyond the optically aided hazard distance of 110 m.
5. An unrestricted building is at a distance that is beyond the aided NOHD from the laser at Terminal A, so no control measures would be required.
6. An unrestricted location at 75 m from Terminal A is not along the beam path of the laser at Terminal A, but it would have to be determined that this location was more than 6 m from the beam path to avoid necessary controls since the location is unrestricted.

Example 18: Assess the optical hazards from the laser at Terminal B at the five locations of interest, assuming the laser emits the maximum output power that meets the Class 3B limit.

Solution:

1. Terminal A: Since the laser at Terminal B is farther than the transmitted *NOHD-M* from that laser, no further controls are necessary. Personnel in this area would also be trained not to use optical aids in the area while the laser at Terminal A could be energized, but that would not protect them from the laser at Terminal B from being energized without their knowledge.
2. Outside the window at Terminal A: Here, the likelihood of window cleaning personnel having and using optical aids must be considered to determine control measures. As it would typically be considered unlikely that people in this location would have optical aids, it is likely that no further control measures would be necessary. An LSO might require a sign visible to window-cleaning personnel notifying them of the possibility of a hazard when using optical aids since this area is within the *NOHD-M* for direct viewing of the laser at Terminal B (and also the laser at Terminal A).
3. Neighboring building: The rooftop of an intermediate building is located $R_I = 140$ m from Terminal B, which is within the *NOHD-M* of 412 m. Because the beam path clears the building by 2 meters vertically, no controls are required to protect people in restricted areas. However, in unrestricted areas, a 6 m vertical buffer is required to be considered inaccessible, and this rooftop position is within the *NOHD-M*. So, it would have to be determined whether the rooftop position was restricted access or not to determine if the system at Terminal B could be used as described.
4. An unrestricted building behind Terminal B would not be at risk from the laser at Terminal B from reflections from the window at Terminal A due to the downward slant of the beam, and the combined distance of 600 m would be beyond the calculated *NOHD-M*, so no control measures would be required.
5. An unrestricted location at 75 m from Terminal A is at a total distance of 375 m along the reflected beam path of the laser at Terminal B, which is beyond the *NOHD-M*, so that no controls would be necessary.

B.3.2.6.5 Optical Fiber Ribbon Cable. When the angle subtended by an array of fibers exceeds $\alpha_{\min}$, e.g., a cable comprised of several spatially separated fibers, extended source criteria may apply. Under these conditions, the MPE is modified by the factor C_E where C_E equals $\alpha/\alpha_{\min}$ and α is the subtended angle. For rectangular images, the average of the two orthogonal source angles serves as the effective source angle. The analysis for determining the appropriate MPE for the array requires determining and comparing the MPE for each fiber and each possible group of fibers in the array. The most restrictive MPE is the appropriate MPE to use for hazard evaluations. One could also proceed by assuming that all the radiant energy emitted by the array is emitted by a single “point” source and use the corresponding unmodified point source MPE. While this method overestimates the potential hazard, one would not have to proceed farther if it does not lead to unnecessarily restrictive controls. Any combination of sources with centers separated by an angle greater than $\alpha_{\max}$ (100 mrad) is considered independent.

Example 19: An optical fiber cable is comprised of two parallel ribbons. Each ribbon is a linear array of 12 equally-spaced fibers. The power in each fiber in the ribbon is 10 mW

(10 dBm). The separation distance along the ribbon is 0.9 mm; the separation distance between each fiber in one ribbon with the nearest fiber in the other ribbon is 1.0 mm. The fibers are all identical, each with a mode field diameter of 10 μm . Determine the hazard when viewing the end of the cable for 10 s if the operating wavelength is 1.330 μm and the viewing distance is 20 cm.

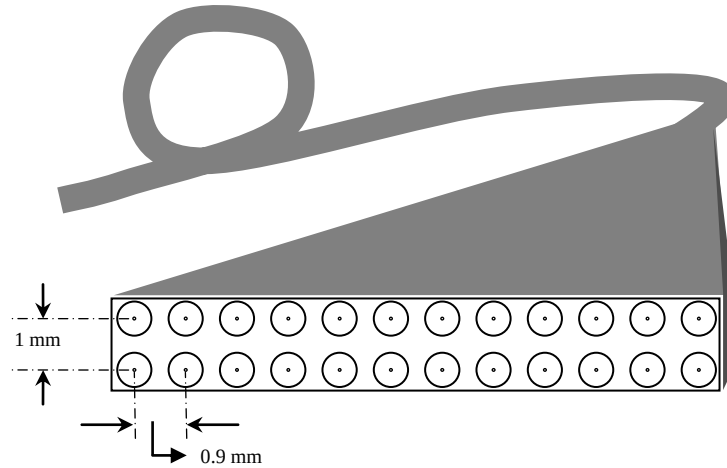


Figure B.3 Optical Fiber Ribbon Cable

Solution. As indicated, the problem is first solved by considering a single fiber, then groups of fibers.

Single fiber: The angle subtended by a single fiber with $\omega_0 = 10 \mu\text{m}$ and $l = 20 \text{ cm}$, is much smaller than $\alpha_{\min}$ (1.5 mrad) and, therefore, small source viewing conditions apply. The corresponding MPE from Table 5a is,

$$MPE:E_{\text{point source}} = 5.0 C_c \times 10^{-3} \text{ W} \cdot \text{cm}^{-2} = 40 \text{ mW} \cdot \text{cm}^{-2}.$$

where C_c is 8.0 for this wavelength (see Table 6). The $MPE:E$ listed is not applicable to the total irradiance of the cable, but to the irradiance produced by a single fiber in the array. The irradiance produced by a single fiber in the cable is found by combining the output power in the fiber and determining the beam divergence and the beam diameter at 20 cm from the fiber end,

$$\phi = \frac{2 \times (1.33 \mu\text{m})}{\pi \times (10 \mu\text{m})} = 0.085 \text{ rad}.$$

Substituting the values from the example we get:

$$D_l = l\phi = (20 \text{ cm})(0.085) = 1.7 \text{ cm}.$$

Therefore,

$$E = \frac{4\Phi_0}{\pi D_L^2} = \frac{4 \times 10 \times 10^{-3} \text{ W}}{\pi (1.7 \text{ cm})^2} = 4.4 \text{ mW} \cdot \text{cm}^{-2}.$$

Thus, the irradiance of a single fiber in the array does not exceed the MPE; in fact, the irradiance is about 11% of the MPE.

Two adjacent fibers: Two adjacent fibers in the same ribbon or in adjacent ribbons subtend angles of 4.5 and 5.0 mrad at the 20 cm viewing distance, respectively. Since $\alpha_{\min}$ is defined to be 1.5 mrad, the combination of fibers is considered an extended source. By reviewing Table 5b, we conclude that we must first determine, T_2 . By reviewing Table 5b, we recognize that T_2 , which is defined in Table 7, must be determined first. Specifically, $T_2 = 10 \times 10^{(\alpha - 1.5)/98.5} = 10.73$ s and 10.85 s for 4.5 and 5.0 mrad respectively. However, the problem asks for the MPE for 10 s, which is less than T_2 . Table 7 provides an expression for C_E for subtended angles between 1.5 mrad and 100 mrad; $C_E = \alpha/\alpha_{\min}$. For an elliptical or rectangular shaped source, the arithmetic mean of the two dimensions is used to compute the effective source angle, α_f . Thus, $C_E = 2.0$ for two adjacent fibers in a single ribbon ($\alpha_f = [4.5 \text{ mrad} + 1.5 \text{ mrad}]/2$), and $C_E = 2.17$ for 2 fibers in adjacent ribbons ($\alpha_f = [5.0 \text{ mrad} + 1.5 \text{ mrad}]/2$). Thus, the smaller MPE (for the 4.5 mrad separation) for 10 s is,

$$MPE \cdot E_{\text{extended source}} = MPE \cdot E_{\text{point source}} \times C_E = 80 \text{ mW} \cdot \text{cm}^{-2}.$$

The beam pattern from the two adjacent fibers is an ellipse with the minor axis equal to the beam diameter, which is 1.7 cm, and the other axis is that beam diameter plus the separation distance between the fibers, which is 0.9 mm. Therefore the two dimensions are 1.7 cm and 1.79 cm. The irradiance is then,

$$E = \frac{4\Phi_0}{\pi D_{L1} D_{L2}} = \frac{4 \times 2 \times 10 \text{ mW}}{\pi (1.7 \text{ cm})(1.79 \text{ cm})} = 8.4 \text{ mW} \cdot \text{cm}^{-2}.$$

The MPE is not exceeded from two fibers in the array; in fact, the irradiance is about 10.5% of the MPE.

Four adjacent fibers: Four adjacent fibers (two in the same ribbon and two in adjacent ribbons) subtend angles of 4.5 and 5.0 mrad at the 20 cm viewing distance. The value of $C_E = 3.17$ for adjacent fibers in a single ribbon and adjacent ribbons ($\alpha_f = [4.5 \text{ mrad} + 5 \text{ mrad}]/2$). Therefore, the MPE for 10 s (for the 4 fibers in a 2×2 array forming a rectangular source) is,

$$MPE \cdot E_{\text{extended source}} = MPE \cdot E_{\text{point source}} \times C_E = 127 \text{ mW} \cdot \text{cm}^{-2}.$$

The beam pattern from the four adjacent fibers forms a rectangle with rounded corners with dimensions equal to 1.79 cm and 1.8 cm, for which the irradiance is,

$$E = \frac{\Phi_0}{D_{L1} D_{L2}} = \frac{4 \times 10 \text{ mW}}{(1.79 \text{ cm})(1.8 \text{ cm})} = 12.4 \text{ mW} \cdot \text{cm}^{-2}.$$

Therefore, the MPE four fibers in the array is not exceeded; in fact, the irradiance is about 9.8% of the MPE.

All fibers in cable: To consider the entire cable, it should be noted that the physical dimensions of the cable may exceed the limiting aperture diameter of 7 mm. Therefore, the emission from

the entire array may not be able to enter the pupillary diameter of the eye, which is simulated by the 7 mm limiting aperture. In fact, the length of the array containing the fibers is $11 \times 0.9 \text{ mm} = 1.32 \text{ cm}$, and the width is 1 mm. The beam pattern from all the fibers forms a rectangle with the smaller dimension equal to 1.79 cm and the other dimension equal to 3.02 cm. The irradiance is then,

$$E = \frac{\Phi_0}{D_{L1} D_{L2}} = \frac{24 \times 10 \text{ mW}}{(1.79 \text{ cm})(3.0 \text{ cm})} = 44.4 \text{ mW} \cdot \text{cm}^{-2}.$$

This irradiance is a little more than 10 times the irradiance from a single fiber, not 24 times the single fiber irradiance as may be thought.

The calculation of the extended source factor should be based on those fibers that contribute to the hazard, which is apparently less than half of those available when a 7 mm measurement aperture is used.

Appendix C

General Examples of Methods of Hazard/Safety Analysis and Work Practices

C.1 Examples of Methods of Hazard/Safety Analysis

Examples of methods of hazard/safety analysis are as follows:

- a) Preliminary hazard analysis (PHA) including circuit analysis. This method may be used in its own right, but is an essential first stage in the application of other methods of hazard/safety assessment.
- b) Consequence analysis, e.g., see IEC 61508
 - 1) Failure modes and effects analysis (FMEA)
 - 2) Failure modes, effects and criticality analysis (FMECA), e.g., see IEC 60812
 - 3) Fault tree analysis (FTA)
 - 4) Event tree analysis (ETA)
 - 5) Hazards and operability studies (HAZOPS)

Appropriate testing should be implemented to supplement the analysis whenever necessary. The method of analysis and any assumptions made in the performance of the analysis should be stated by the manufacturer/operator.

C.2 Work Practices for FSOCS

C.2.1 General Considerations. These general work practices are precautions that should be applied when servicing and installing any FSOCS. In addition, the work practices detailed in C.2.2 should be applied as appropriate.

The following practices should be applied when working on any free space optical communication system:

- a) *Alignment:* Alignment, installation and testing of the system should be carried out with the system operating at the lowest possible output power, and not exceeding Class 1M or 2M, as appropriate.
- b) *Maintenance/Operation:* Follow only manufacturer-provided instructions for operation and routine maintenance of the system.
- c) *Service/Installation:* Follow only manufacturer-provided instructions for installation and for service and repair on the system. Disable safety features as infrequently as possible. Ensure that safety features are reinstated before the system is put back into normal use.
- d) *Cleaning:* Use only manufacturer-provided methods for cleaning optical components of the laser system, if allowed at all. This will normally involve disabling the equipment, or at least stopping laser emission.

- e) *Modifications*: Do not make any unauthorized modifications to any system or associated equipment.
- f) *Label damage*: Report damaged or missing safety labels to person appointed to maintain equipment.
- g) *Key control*: For equipment with key control, keys should be placed under the control of a person appointed by management who should ensure their safe use, storage and overall control. Spare keys should be retained under strict control by an authorized person. Authorization is given by the installing or operating organization as appropriate.
- h) *Test equipment*: Use only approved and calibrated test equipment, e.g., optical loss test sets, optical time domain reflectometers, optical power meters.
- i) *Signs*: Posting additional area warning signs may be appropriate in certain circumstances, e.g., temporary warning signs during service.

C.2.2 Additional Work Practices for Class/Access Level 1M, 2M, 3R, 3B and 4 Systems. If access to Class/Access level 1M, 2M, 3R, 3B or 4 optical energy is possible, the following additional practices should be followed:

- a) All general working practices defined in C.1.
- b) Except for Class/Access level 1M or 2M, only trained personnel should have access to the open beam portion of the system.
- c) Do not stare into fiber connectors, the ends of broken fibers, or into any laser beams with the naked eye or with any optical aid (unless approved by the installing or operating organization LSO as appropriate), and do not point the laser beam at people.
- d) Any viewing and alignment aids used should have valid calibration and safety labels, and should be equipped with engineering controls such as filters to prevent exposure to levels above the MPE in the appropriate wavelength bands.
- e) Where feasible, alignment and testing should be carried out using Class/Access level 1 or 2, and
- f) There should be no instance where exposure to optical energy in excess of Access Level 1M, 2M and 3R is necessary.
- g) Education and Training.
 - 1) Installation, operating, maintenance and service organizations which might include persons in the vicinity of FSOCS should be notified of hazards through labels, signs and training as appropriate. In addition, persons installing and maintaining Class 3B and 4 transmitters should be informed of at least the following:
 - i. Background information on FSOCS
 - ii. Safety information concerning the laser classification system and access level identification
 - iii. Identification of the biological effects and potential hazards to the eye and skin from laser exposure

- iv. Procedures that must be followed for safe installation and maintenance of these systems, and
- v. Explanation of possible effects if safety rules are not followed

C.3 Work Practices for OFCS

C.3.1 General Considerations. Optical amplifiers, which can boost the signal well above 50 mW, are being widely used in contemporary systems. Moreover, some optical amplifiers use pump lasers of the appropriate wavelength to affect amplification of the input (signal) wavelength, e.g., the pump wavelengths for a 1.55 μm amplifier are typically 1.48 or 0.98 μm . The pump lasers, which may be remote from the amplifier, can also operate well in excess of 50 mW. Therefore, it is good practice that whenever working on a disconnected or unterminated optical fiber, procedures are in place to assure that the system is de-energized before proceeding and remains de-energized throughout the service procedure.

C.3.2 Viewing. Although viewing the end of a disconnected energized optical fiber with the unaided eye at distances greater than a few cm from the connector of a Hazard Level 1M, 2M, or 3R OFCS may not cause injury to the eye, this procedure should be avoided since it can result in developing a potentially dangerous habit. The following practices should be applied when working on any OFCS:

- a) Except for Hazard Level 1 OFCS, the end of an optical fiber or optical connector should not be viewed with the unprotected eyes.
- b) For Hazard Levels 1M, 2M, 3R and 3B, only filtered viewing aids approved by the operating organization should be used.
- c) Ribbon fiber ends cleaved as a unit may produce a higher hazard level than that of a single fiber. Therefore, do not cleave ribbon fiber as a non-separated ribbon, or use ribbon splicers, unless authorized by the installation or operating organization.
- d) Verifying continuity of optical fibers by shining a flashlight into one end and viewing the other end is not recommended. The recommended method for verifying continuity is to use the appropriate optical test set.
- e) Viewing the end of a fiber that is suspected to be energized should only be done with an indirect image converter or similar device.
- f) Unterminated single or multiple fibers that are not being worked on should be covered with material appropriate for the hazard level of the OFCS. Suitable covering methods include the use of a splice protector, tape or suitable end caps.

C.3.3 Cleaning. Proper cleaning is important, especially for high-power systems, e.g., over 1 W in the fiber, in order to mitigate the possibility of extremely high temperatures that in some cases may lead to “fiber-fuse” phenomenon when connected or spliced. The following practices should be followed when cleaning fiber ends and connectors:

- a) Use only methods approved by the operating organization for cleaning and preparing optical fibers and optical connectors.

- b) Use adequate ventilation when using solvents and chemicals for stripping, cleaning and splicing optical fibers.
- c) Use the least hazardous solvents for the task.
- d) Refer to the Material Safety Data Sheets (MSDS) for each solvent or chemical that will be used.

C.3.4 Fiber Bending-radius. Excessive bending of an optical fiber can form a risk of both mechanical failure due to bending stress as well as a local heating point at high-power levels.

C.3.5 Board Extenders. Board extenders should not be used on optical transmitter or optical amplifier cards, i.e., do not power optical sources when they are outside of the equipment shelf.

C.3.6 Maintenance. Follow only instructions approved by the operating or installation organization when installing, servicing or maintaining the OFCS.

C.3.7 Test Equipment. There are, at present, several different categories of test sets in use with OFCS, e.g., optical loss test sets (OLTS), optical time domain reflectometers (OTDR), optical bandwidth test sets. Although some OTDRs use a Class 1 or Class 1M laser, some may use Class 3B lasers, as do typical OLTSs. Since an OFCS test set is itself considered an OFCS, the control measures in ANSI Z136.1 that are applicable to the class of the test set should also apply since it can be operated separate from the OFCS.

- a) Use test equipment of the lowest class necessary and practical for the task. Do not use test equipment of a higher class than the OFCS hazard level at the location where this equipment is being used.
- b) When using test equipment in an OFCS that contains optical amplifiers, the amplifier can boost the output power of the test set to a higher class. This should be taken into account and the above practices applied accordingly.

C.3.8 Modification. Do not make any unauthorized modifications to any OFCS or associated equipment.

C.3.9 Key control. For OFCS, or portions of an OFCS with key control, the keys should be placed under the control of a person appointed by the operating or installation who should ensure their safe use, storage and overall control. Spare keys should be retained under strict control.

C.3.10 Alarms. System alarms, especially those indicating that the APR or any other safety system is inoperable, should be responded to so that repair takes place within a specified time commensurate with the OFCS hazard level.

C.4 References

ANSI Z136.1-2007, American National Standard for the Safe use of Lasers.

ANSI Z136.2-1997, American National Standard for the Safe use of Optical Fiber Communication Systems Utilizing Laser Diode and LED Sources.

IEC 60812-2 (2006), Analysis Techniques for System Reliability - Procedure for Failure Mode and Effects Analysis (FMEA), International Electrotechnical Commission, Geneva.

IEC 60825-2 (2007), Safety of Laser Products - Part 2: Safety of Optical Fiber Communication Systems (OFCS), International Electrotechnical Commission, Geneva.

IEC 60825-12 (2005), Safety of Laser Products - Part 12: Safety of Free Space Optical Communication Systems used for Transmission of Information, International Electrotechnical Commission, Geneva.

IEC 61508 Series, Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems, International Electrotechnical Commission, Geneva.

ITU-T Supplement 39 (2006), Series G: Transmission Systems and Media, Digital Systems and Networks: Optical System Design and Engineering Considerations, International Telecommunications Union, Geneva.

Appendix D

OCS Risk Assessment Philosophy—Clarification of OCS Terminology: Hazard Classification, Access Level and Hazard Level

D.1 General

There are several concepts applied in this OCS standard that may appear similar or redundant. This appendix treats the philosophical distinctions and differences between *laser class*, *access level*, *hazard level* and related terms of MPE, AEL, etc. Wherever possible, the ANSI ASC Z136 Standards Subcommittee 2 on OCS Safety attempted to be consistent with the most current editions of IEC 60825-1, 60825-2 and 60825-12 as well as ANSI Z136.1 at the time of preparation. For manufacturer product certification see IEC 60825-1.

D.2 Hazard Class, Hazard Level and Access Level

D.2.1 Hazard Class (All OCS). The term *hazard class* refers to a scheme by which, based on emission levels, any laser product or emitter can be grouped with respect to its safety during normal operation. Each hazard class is defined by the accessible emission limit (see for example, the tables in IEC 60825-1). Classes range from Class 1, which is “eye-safe” under reasonably foreseeable conditions, to Class 4—the most hazardous Class—which covers all products exceeding the AEL for Class 3B. In IEC 60825-1, the classification of products is based on reasonably foreseeable operating conditions including single-fault conditions. Essentially, all OFCS are Class 1, because under intended use conditions the energy is always contained within the fiber.

D.2.2 Access Level (FSOCS). The term *access level* is used in this standard to refer to the potential hazard from FSOCS laser emissions at any location along the beam path that may be accessible during maintenance or service or in the event of a system failure or unauthorized intrusion along the beam path. The assessment of the access level uses the class accessible emission limit (AEL) tables used for product classification, but are applied for hazard evaluation—often with different measurement conditions than those used in product classification. The assessment of access level is given in 3.5.2. The assessment can be an actual measurement or be based upon calculation of emitting powers and known time constants. This approach is equivalent to applying the MPEs for the worst-case exposure duration when determining Access Level 1.

A total FSOCS may be any class, but normally is installed so that the public has access only to Access Level 1.

D.2.2.1 Installation Protection System (IPS). This standard allows the use of installation protection systems (IPS) to produce a lower hazard level and access level (see 3.2.2.4).

D.2.3 Hazard Level (OFCS). *Hazard level* is a term used in this standard to refer to the potential hazard from OFCS laser emissions at any location in an end-to-end fiber optic communication system that may be accessible during maintenance or service or in the event of a

system failure or fiber break/disconnection. The assessment of the hazard level uses the class accessible emission limit (AEL) tables used for product classification, but are applied for hazard evaluation—often with different measurement conditions than those used in product classification. The assessment of hazard level is given in 3.4.1. The assessment can be an actual measurement or be based upon calculation of emitting powers and known time constants.

A total OFCS can be regarded as a Class 1 laser product because, under normal conditions, the emissions are completely enclosed (like a laser printer) and no light should be emitting outside the protective housing (cable sheath, connectors, etc.). It is not until the fiber becomes broken or an optical connector unplugged that someone might be exposed to a level of optical radiation that is potentially hazardous (if the internal emitters or amplifier outputs are of high enough power). Therefore, for each optical output port, the hazard level must be assessed.

D.2.3.1 Automatic Power Reduction (APR). This standard allows the use of automatic power reduction (APR) techniques to achieve a lower (less hazardous) hazard level based on the normal power in the fiber and the speed of automatic power reduction (see 3.2.2.4).

D.3 Maximum Permissible Exposure (MPE)

MPE values are applied in occupational and environmental health to determine the risk of human exposure at a particular location or locations, but these exposure limits are generally only applied when questions arise with regard to routine intentional exposure or when reconstructing an exposure in an accident setting. Instead, the laser hazard classification schemes (essentially the same in ANSI Z136.1 and IEC 60825-1) are used to determine control measures to simplify the hazard evaluation process. For product safety standards (IEC 60825-1, FLPPS), it is product emission, rather than exposure that is regulated. The product safety standards publish Accessible Emission Limits (AELs) used by the manufacturers to classify their laser products. Because the manufacturer does not know where and for how long someone might be exposed to the emitted laser radiation, product-safety standards specify very specific AEL measurement distances and measurement apertures are used to assure reproducibility and uniformity – independent of testing laboratory or manufacturer’s quality assurance department. Standards committees have exhaustively debated the best measurement conditions that simulate worst-case viewing conditions and durations for a wide range of different types of viewing conditions. It therefore must be emphasized that the specified measurement conditions are intended to cover more viewing conditions and distances than those actually specified (see Sliney et al., 2007).

D.3.1 Angular Subtense. A common misconception is that once the angular subtense of the source is determined for unaided viewing at 10 cm (or even at 2 m), this angular subtense can be multiplied by the optical power of a telescope to determine the angular subtense of the source for optically aided viewing. This ignores the fact that a telescope would never be used at extremely close distances—certainly not at a mere 2 m! In fact, there is no direct relationship, and using this method will produce an artificially high MPE and its use could lead to an overexposure from a laser beam. Experiments were conducted to verify basic principles for the proper determination of an extended source MPE (see Marshall et al., 2007).

D.4 Hazard Classification

Hazard classification of almost all lasers can be determined from measurements of the CW radiant power or energy per pulse through two apertures located at two different reference distances from the laser and assuming that the laser is a “point source.” These two apertures and distances are designed to obtain radiant power/energy that may injure the cornea at certain wavelengths or enter the eye at retinal-hazard wavelengths and pose potential ocular hazards for a person whose eye is in the beam with or without the assistance of optical viewing aids. The greatest challenge for laser safety standards committees has been to provide a reasonably simple, straightforward set of measurement apertures and measurement distances to simulate reasonably foreseeable, worst-case viewing conditions for all foreseeable types of intra-beam viewing. Until recent editions of the standards, viewing at very close proximity with optical aids within a few cm of the laser output was not considered, and only unaided viewing at 10-20 cm was considered. Today, three conditions are considered, Condition 1 using telescopes, Condition 2 using magnifiers, and in the second edition of IEC 60825-1, the term “Condition 3” is used for near-point unaided viewing. The ANSI standard currently treats Condition 2 and 3 as essentially the same.

D.4.1 Unaided Viewing. The CDRH standard (FLPPS) and ANSI Z136 standards in past decades recommended a closest measurement distance of 20 cm to account for the fact that most younger persons can focus (“accommodate”) on an object as close as 20 cm; this is termed the “near-point of accommodation.” To be more conservative, the IEC (and later, the ANSI) Committee recognized that a small, but significant fraction of the populations, as well as most children, could have a near point as close as 10 cm, and 10 cm has since been standardized as one default measurement distance to account for the closest reasonable viewing distance for the unaided eye and a 7-mm aperture is placed at this distance for comparison with AELs in the retinal-hazard region.

D.4.2 Condition 1. To simulate optically aided viewing by telescopes, a limiting aperture size was designed to cover a wide range of telescopes at potential viewing distances, but to make the classification measurement possible in an indoor laboratory setting, the IEC telescopes cannot focus closer than ~ 6-10 meters, and would not be realistically so close to a laser aperture. This measurement condition at 2 m is termed “Condition 1” and is intended to account for all intrabeam viewing at distance by telescopes. It is considered to cover reasonably foreseeable telescopes up to approximately 80 mm in diameter (since any realistic telescope also attenuates some of the energy). At one time in the 1980s, the different laser standards actually used an 80-mm aperture, but probabilistic risk analysis and recognition of the likelihood of perfect alignment, sufficient proximity to collect as much energy at a considerable distance as a 50-mm aperture at 2 m, and recognition of reduced throughput led to the standardized default classification aperture of today which collects more energy than a real telescope at realistic intrabeam viewing distances. Although the reference position of the laser source in the IEC standard has been the location of the “apparent source,” which has been of some importance for viewing of a highly diverging beam, most laboratories simply place the 50-mm aperture at 2 m from the laser output aperture. The 2 m distance was also favored by some committee members as to be sufficiently distant so that much of the collateral optical radiation (pump light, gas-discharge glow, etc.) and diffuse laser scatter exiting, which was highly diverging, would not be collected in this measurement (but if hazardous, it would have to be measured by appropriate

techniques), and the 2 m distance could be accommodated in most room sizes characteristic of indoor test laboratories. It should be emphasized that for the common 7X50 binocular (7-power with 50-mm objective), this measurement condition is highly conservative.

D.4.3 Condition 2. The ANSI Z136 Committee also considered that a measurement with a 7-mm limiting aperture at 10 cm from the source to be adequate to account for the use of common hand-held magnifiers, where viewing a diverging beam—as from an optical fiber connector—would require the unaided eye of a person with normal 20/20 vision using a moderate power magnifier (2.5X) or a myopic person, to focus on the fiber tip. The default condition of a 7-mm aperture placed at a distance of 10 cm from an apparent source is completely unrealistic to simulate a real optically aided viewing condition, since one must have sufficient ambient illumination to focus sharply on the fiber tip or a laser diode emitter, and the pupil size would more likely be about 3 mm. Furthermore, the eye-loupe or magnifier would transmit less than 100%. Thus the 7-mm aperture placed at 10 cm realistically has the same geometrical collection of energy from a fiber tip as a 3-mm aperture placed at 4.2 cm to simulate the viewing condition with a 5.9X eye loupe, and by considering transmission losses, etc., the use of a 7X eye loupe at 3.5 cm was adequately covered. The IEC TC76 Committee chose to use a 7 mm aperture at 7 cm to simulate the geometrical collection of a 7X eye loupe and have a default condition of a 7 mm aperture at 7 cm for Condition 2. Using an eye-loupe of greater than 7X is not a reasonably foreseeable viewing condition for any laser application, except for inspection of optical-fiber connectors. For this reason, the ANSI Z136 Committee determined that the specialized Condition 2 that would assume high-power (10-20X) magnification should be treated in a special application standard: ANSI Z136.2, *Safe Use of Optical Fiber Communication Systems (OFCS) Utilizing Laser Diode and LED Sources*, which was first issued in 1988, and reissued in 1997.

This approach of dealing with high-power magnifiers (and including LEDs used in OFCS) was proposed by the US Delegation to IEC TC76 in 1992, but unfortunately, IEC TC76 included this viewing condition (and included all LEDs) as a general requirement in the 1993 edition of IEC 60825-1. The IEC standard included this “Condition 2” to account for the potential use of higher power magnifiers which could be used to view extremely diverging beams at extremely close viewing distances, and added a measuring distance that varied with source size, but could be as close as 1.4 cm for a “point source” such as most single-mode fibers with a 7-mm aperture for visible or near infrared laser beams. For viewing “extended source lasers,” applying Condition 2 involved much more complexity. Finally, in 2003, the IEC TC76 Committee fully recognized the needless complexity and over-statement of risk with the Condition 2 formulations of the measurement distances between 1.4 and 10 cm. Although members differed in their detailed rationale (even considering magnified image motion), a new default measurement distance of 7 cm with a 7-mm aperture (simulating, for example a 3.5 mm pupil viewing with a 7X microscope of 100% efficiency) at its focal position of 3.5 cm. The ANSI Z136 Committee chose to maintain 10 cm as the reference position and deal with high-power magnifiers used in OFCS inspection only in the ANSI Z136.2 standard. In this standard, the default condition for Condition 2 is to measure the power entering a 7-mm aperture at 7 cm rather than the normal approach of measuring the power entering a 7-mm aperture at 10 cm. This is a compromise for optical cables and other extended sources, since this measurement approach will overstate the risk. It is always possible to evaluate the optically aided viewing of an extended source

rigorously by calculating the magnified angular subtense of the source, etc. using the general MPE given in Table 5a.

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Appendix E

Medical Surveillance

E.1 Other Medical Examinations

The eye examination is not designed to be part of a complete medical examination in which the total visual system is evaluated. The particular visual parameters selected for measurement/examination are those deemed necessary for the particular job and/or those which may be affected by hazardous exposure to OCS radiation. See ANSI Z136.1 for additional information.

Medical surveillance should be considered for those who are clearly known to be at risk from particular kinds of laser radiation. Medical surveillance is not recommended for personnel installing or servicing OCS containing Class 1, Class 1M, Class 2, Class 2M or Class 3R lasers as defined in Section 3.2, but should be considered for personnel installing or servicing OCS containing Class 3B and Class 4 lasers. Further information is provided in Appendix E.

E.2 Medical Surveillance

The purpose of the medical surveillance program is:

- a) To establish a baseline of ocular conditions against which any suspected damage can be measured in the event of accidental exposure to OCS emission.
- b) To detect and document possible ocular damage as soon as possible.

A medical surveillance program is mandatory not for OCS personnel (see 6.2.2).

E.2.1 Rationale. The rationale for medical surveillance requirements and specific information on recommended medical examinations are based on the guidelines provided in ANSI Z136.1.

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