PD IEC/TR 60825-17:2015

BSI Standards Publication

Safety of laser products

Part 17: Safety aspects for use of passive optical components and optical cables in high power optical fibre communication systems

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The UK participation in its preparation was entrusted to Technical Committee EPL/76, Optical radiation safety and laser equipment.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Published by BSI Standards Limited 2015

ISBN 978 0 580 79373 8
ICS 31.260; 33.180.01

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 October 2015.

Amendments/corrigenda issued since publication

Date	Text affected

IEC TR 60825-17

Edition 2.0 2015-10

TECHNICAL REPORT

Safety of laser products –
Part 17: Safety aspects for use of passive optical components and optical cables in high power optical fibre communication systems

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 31.260; 33.180.01 ISBN 978-2-8322-2959-0

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SAFETY OF LASER PRODUCTS –

Part 17: Safety aspects for use of passive optical components and optical cables in high power optical fibre communication systems

FOREWORD

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IEC TR 60825-17, which is a Technical Report, has been prepared by IEC technical committee TC 76: Optical radiation safety and laser equipment.

This second edition cancels and replaces the first edition published in 2010. This edition constitutes a technical revision.

The changes with respect to the previous edition include changes to harmonize with SC86A and SC86B documents.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
76/510/DTR	76/526/RVC

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 60825 series, published under the general title *Safety of laser products,* can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

The rapid growth of applications such as the internet and business intranets requiring high bitrates has caused a dramatic increase in the need for high capacity data connections. This increase in capacity has resulted in a requirement for a corresponding increase in power levels used in optical fibre communications systems. There are a number of areas of concern including but not exclusively the use of erbium-doped fibre amplifiers (EDFA), high power dense wavelength division multiplexing (DWDM) systems, and Raman amplification.

The power levels associated with these systems are typically greater than 500 mW (i.e. Class 4), but some studies have shown additional thermal effects can occur at lower powers. These additional thermal and related hazards mean that it is necessary to address a number of new issues. It should be noted that the vast majority of these systems use single-mode fibre.

SAFETY OF LASER PRODUCTS –

Part 17: Safety aspects for use of passive optical components and optical cables in high power optical fibre communication systems

1 Scope

This part of IEC 60825 recommends safety measures to protect against effects caused exclusively by thermal, opto-mechanical and related effects in passive optical components and optical cables used in high power optical fibre communication systems.

This part of IEC 60825 does not apply to the use of high power optical systems in explosive atmospheres or the use of optical fibres in material processing machines. Throughout this part of IEC 60825, a reference to ‘laser’ is taken to include light-emitting diodes (LEDs) and optical amplifiers.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60825-1:2014, *Safety of laser products – Part 1: Equipment classification and requirements*

IEC 60825-2:2004, *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*
IEC 60825-2:2004/AMD1:2006
IEC 60825-2:2004/AMD2:2010[1]

ITU-T Recommendation G.664, *Optical safety procedures and requirements for optical transmission systems*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
automatic laser shutdown
ALS
technique (procedure) to automatically shutdown the output power of laser transmitters and optical amplifiers to avoid exposure to hazardous levels

3.2
automatic power reduction
APR
feature of an optical fibre communication system (OFCS) by which the accessible power is reduced to a specified level within a specified time, whenever there is an event which could result in human exposure to radiation, e.g. a fibre cable break

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[1] A consolidated edition 3.2 exists, including IEC 60825-2:2004 and its Amendment 1 and Amendment 2.

Note 1 to entry: The term “automatic power reduction” (APR) used in this document encompasses the following terms used in recommendations of the International Telecommunication Union ITU:

- automatic laser shutdown (ALS);
- automatic power reduction (APR);
- automatic power shutdown (APSD).

[SOURCE: IEC 60825-2:2004, 3.2]

3.3
controlled location
location with controlled access
accessible location where an engineering or administrative control is present to make it inaccessible, except to authorized personnel with appropriate laser safety training

[SOURCE: IEC 60825-2:2004, 3.13]

3.4
hazard level
potential hazard at any accessible location within an OFCS, based on the level of optical radiation which could become accessible in a reasonably foreseeable event, e.g. a fibre cable break

Note 1 to entry: It is closely related to the laser classification procedure in IEC 60825-1.

[SOURCE: IEC 60825-2:2004, 3.4, modified — Supplementary information has been moved from the definition to a Note to entry.]

3.5
high optical power
optical power of 500 mW or greater potentially capable of causing damage to fibres, optical components or systems (typically Class 4)

Note 1 to entry: 500 mW is recommended partly as it is the breakpoint between Class 3B laser products (unlikely to cause fire) and Class 4 laser products (may cause fire).

Note 2 to entry: Studies have shown damage is significantly more likely at powers in excess of 1 W, but damage has also been shown to occur at powers as low as 200 mW – see [1] and [2][2].

3.6
loss of continuity of an optical link
event which may cause hazardous optical power levels to be emitted from some point along the path of an optical transmission system

Note 1 to entry: Common causes of loss of continuity of an optical link are a cable break, equipment failure, connector unplugging, etc.

3.7
optical fibre communication system
OFCS
engineered, end-to-end assembly for the generation, transfer and reception of optical radiation arising from lasers, LEDs or optical amplifiers, in which the transference is by means of optical fibre for communication and/or control purposes

[SOURCE: IEC 60825-2:2004, 3.18]

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[2] The numbers in square brackets refer to the Bibliography.

3.8
restricted location
location with restricted access
accessible location that is normally inaccessible by the general public by means of any administrative or engineering control measure but that is accessible to authorized personnel who may not have laser safety training

[SOURCE: IEC 60825-2:2004, 3.14]

3.9
unrestricted location
location with unrestricted access
accessible location where there are no measures restricting access to members of the general public

[SOURCE: IEC 60825-2:2004, 3.15]

4 Recommendations

4.1 General considerations – the background to optical fibre damage at high powers

When optical fibres are operated at high power levels (typically > 500 mW), fibres and optical connectors can be damaged. In optical communications systems the optical power is transmitted in CW mode or at high repetition rates, and therefore catastrophic damage is predominantly caused by thermal mechanisms. It has been shown that several effects can cause high optical power-induced damage of single-mode fibre systems leading to fibre failures. Systems employing high optical power operation in fibres, connectors, collimators and attenuators thus carry additional safety concerns. For example, local heating in contaminated connectors/attenuators carrying high optical power can pose a potential fire hazard to surrounding materials, depending on the flammability of those materials.

IEC TR 61292-4 provides extensive guidance on the following topics (see also [3]):

- fibre fuse and its propagation;
- loss-induced heating at connectors or splices;
- connector end-face damage induced by dust/contamination;
- fibre coating burn/melt induced by tight fibre bending.

4.2 Fibre coating damage occurring when bending at high powers

Studies [4–12] on tight fibre bending at high power show that coating ageing can occur slowly and catastrophic damage effects can occur after hundreds of hours. The main implication is that damage testing must be carried out for sufficiently long times; some early experiments were conducted over short times, possibly leading to incorrect conclusions. IEC TR 62547 should be followed for the measurement of high power damage sensitivity at bends.

As discussed by Bigot-Astruc, M et al. [6] and in IEC TR 62547, a fast method of testing for potential damage effects at high powers can use a thermal imaging camera. Equilibrium temperatures are established relatively quickly, allowing the consequences of high power to be rapidly assessed. The issues concerning high power at tight bends arise because of exposure of the fibre coating to high power at or near to the bend. Coating ageing occurs at a rate determined by bend loss, launch power, environmental conditions and coating resilience. New bend insensitive fibre designs – described by the ITU-T Recommendation G.657 specifications and IEC product specification IEC 60793-2-50, category B6 fibres – are a possible solution (see Section 2.5 in [7] and Subclause 4.5.3.2 of IEC TR 62547:2013). However, for extreme situations more resilient coatings may also be required.

The long-term damage effects of high power in other optical components, described for example in 4.7, show the need to consider the implications of high power damage research, as discussed in IEC TR 62547.

Well documented experiences of the ageing of coatings of fibres in tight bends under high power have shown that catastrophic effects can occur after hundreds of hours [3]. Coating ageing has been seen to be the trigger for catastrophic failure; the use of thermal imaging cameras as described by Bigot-Astruc, M et al. [6] and in IEC TR 62547 has shown that equilibrium temperatures can be a good indicator of lifetime and such cameras can be used to reduce the time required for high power evaluation and damage testing. Also, note that the rate of fibre coating ageing is usually temperature dependent, thus ambient environmental conditions may affect component resilience – see Sikora et al [8].

4.3 Information on automatic power reduction (APR)

Extra recommendations for automatic power reduction (APR) are made because APR will become more critical in systems where fire, fibre and connector damage, and other hazards are possible if fibre is mishandled. These recommendations may include additional network management and administrative controls, electrical connectivity testing for higher reliability of APR, and others. OFCSs employing high optical power may necessitate the incorporation of APR within one section of a main optical path in the event of recovery from the loss of optical power or loss of continuity of an optical link within that particular section.

Automatic power reduction should be specified and shown to have a high level of reliability for systems using high optical power operation in fibres at all installed locations. IEC 60825-2 describes an ‘adequate’ level of reliability for APR systems (500 FITs).

NOTE IEC 60825-2 defines FITs as “an indicator of reliability defined as the number of failures per 10^9 h.”

Automatic power reduction should take into account all optical power present in both directions on the optical path, as described in the following excerpts reproduced with permission from Recommendation ITU-T G.664 (10/2012):

> “APR techniques are necessary when the sum of operational power (main optical signal) and pump-laser output power at the optical interfaces exceeds the applicable hazard levels defined in IEC 60825-2. The total power is the sum of the power in any one direction from all optical channels, the power from all pump-lasers and the power from optical auxiliary channels (OAC), if used. Within the context of this Recommendation, an optical supervisory channel (OSC) is regarded as a specific case of an OAC.
>
> After power reduction, the total power level (the sum of the power from all optical channels, the remaining power from pump-lasers and power from an OAC) must be within hazard level 1M (or 3B in controlled locations), but reduction of the total power to hazard level 1 or even complete shutdown is acceptable.
>
> Optical transmission systems employing distributed Raman amplification need extra care to ensure safe optical working conditions, because high pump powers (power levels above +30 dBm are not uncommon) may be injected into optical fibre cables. Therefore, it is recommended to use APR in all systems employing distributed Raman amplification with operational power levels above hazard level 1M (or 3B in controlled locations). In this way hazards from laser radiation to the human eye or skin, and potential additional hazards such as temperature increase (or fire) caused by locally increased absorption due to connector contamination or damage are avoided. Further guidance is provided by IEC TR 61292-4.
>
> Distributed Raman-based systems differ from discrete optically amplified systems due to the possible presence of pump lasers at the "receiving" side of a link, launching high optical powers backward into the fibre. In order to ensure that the power levels radiating from broken or open fibre connections are at safe levels, it is necessary to reduce the power not only from the main optical signal sources but also from all pump lasers employed, including the reverse pump lasers. Because the operating wavelength of the Raman pump lasers is usually different from the actual data signal, separate assessments

at various wavelengths may need to be made both at pump laser wavelength and at main signal wavelength."

ITU-T G.664, Appendix II.3 describes automatic laser shutdown (ALS) and restart procedures for single channel synchronous digital hierarchy systems with the additional presence of optical amplification.

Operational aspects of APR should also comply with all relevant subclauses in IEC 60825-2, i.e. "Automatic power reduction (APR) and restart pulses" and "Disabling of the APR".

4.4 Information for manufacturers, operating organizations and users

Due to the potentially increased hazards arising from higher optical powers, additional user information may be needed. Manufacturers of high optical power OFCS, turnkey end-to-end high optical power systems or subassemblies intended to be incorporated into high optical power systems should ensure that the equipment satisfies IEC 60825-2 and the applicable advice of this Technical Report.

The laser radiation hazards present in high optical power systems and detailed safety precautions necessary to prevent exposure to hazardous laser radiation should be contained in the user manual and installation instructions. The organization responsible for the installation and servicing of high optical power OFCS should follow the manufacturer's instructions for installation of equipment in a manner that will ensure that the accessible radiation satisfies the applicable requirements of IEC 60825-2 and the recommendations of this Technical Report, under all reasonably foreseeable conditions.

The operating organization has the ultimate responsibility for the safety of the high optical power end-to-end system. This includes the determination of the location type, i.e. restricted or unrestricted location (defined by IEC 60825-2), at all accessible locations of the entire high optical power OFCS and ensuring that access to any location is appropriately controlled with respect to laser safety.

At any location in a high optical power OFCS where access to a fibre end or a connector is foreseeable, instructions should be provided to the operator or other persons having access. These instructions should include directions to avoid direct exposure to laser radiation. It may also be necessary to consider the need for the use of appropriate laser safety eyewear.

Only persons who have received appropriate training in optical fibre and high power hazards should be allowed to operate high optical power OFCS.

The operating organization should provide appropriate training in laser safety for persons responsible for ensuring that all required markings, protection and safeguards are incorporated in a hazard level 3B location of a high optical power OFCS.

In high optical power systems, losses due to high power absorption can produce elevated temperatures which cause damage and possible ignition. Therefore, those persons dealing with optical components intended for use in high optical power systems, i.e. connectors, attenuators, collimators, splices, etc., should have received appropriate laser safety training according to IEC 60825-2 and IEC TR 61292-4.

The following instructions are relevant to fibres carrying high optical powers and can be used in addition to already published documents which could include IEC 60825-2, IEC TR 62547 and IEC TR 62627-01. Instructions should be provided to personnel handling connectors in high optical power systems. The following are examples.

Connector end-face:	Do not touch connector end face, and clean each connection with appropriate cleaning techniques.
Connection:	Caution: Note any anti-rotation keys or similar locating features.
Dust cap:	It is recommended that dust caps be removed only during operation (to protect connectors from contamination).
Bending and twisting:	Refer to IEC TR 62547.
Test/Check:	Checks should be made for any contamination or damage to connectors or fibre ends. A high magnifying power viewing microscope (with approved attenuating filters to eliminate the possibility of eye exposure to unsafe levels of optical radiation) or an indirect viewing instrument should be used. Use only approved attenuating direct viewing magnifying instruments. IEC 61300-3-35 provides guidance on end-face inspection and IEC TR 62627-01 on cleaning.
Personal safety:	It is recommended that high power lasers be powered down before opening connectors or commencing splicing procedures. The recommendations of this document do not supersede those in IEC 60825-1 or IEC 60825-2.
Front face of cable and connector protection:	Where practical, power the laser off. Exercise care when cleaning.

When optical instruments or viewing optics are not used, devices of hazard level 1 or 1M are considered safe to the retina but risks to the anterior parts of the eye or cornea may exist. Additionally, they may be hazardous if the user employs non-attenuating optical instruments or viewing optics within the beam. It is recommended to use indirect viewing instruments in all cases.

4.5 Fibre and connector damage induced by high optical powers

4.5.1 Fibre fuse and other effects

Optical connectors can fail in high optical power transmission systems, as the end surface of the glass core of the optical fibre can be destroyed due the very high optical power density. Exposure to high temperatures (potentially in excess of 1 000 °C) can cause a tension crack and destroy the connector. Destruction of the fibre can also be caused by a rapid vaporization of contaminants, leading to a micro-explosion/laser-induced melting of fibre core.

The high power density can also initiate a catastrophic failure in the core area of the connector, causing a 'fibre fuse' effect along the cable, which is considered to be due to a high temperature loss increase by SiO ion absorption model. The threshold power for propagation of ‘fibre fuse’ is shown to be 1,2 W or more in IEC TR 61292-4. This process may reach temperatures sufficient to vaporize glass and induce bubbles and voids in the fibre core and may make further optical transmission impossible. In the 'fibre fuse', the optical fibre can be destroyed at a velocity of approximately 1 m/s over a length of several hundred metres (depending on the laser power present). In the event of fibre melting, the high temperatures reached also pose a risk of fire in the fibre coating, any matching or other fluid or gel filling, isolation material, and any surrounding flammable materials.

NOTE 1 1,2 W is given as a threshold for propagation of the fibre fuse effect. However, the fibre fuse effect is a power density related phenomenon and so can be fibre dependent.

The transmission of high optical power through single and multimode fibres raises new issues for fibre manufacturers and manufacturers of in-line components. Reliable connectors provide minimum attenuation of the transmitted signal but minor losses can be caused by mismatch of the fibre core parameters (e.g. numerical aperture/diameter) or lateral/angular misalignment. Energy lost due to fibre misalignment may not necessarily reduce connector reliability, as the energy is dissipated through fibre cladding – however this dissipated energy may cause heating in the adhesives and/or the ferrule.

If shuttered connectors are used, then the temperature rise on the surface of the shutter, flammability, and exposure time of the shutter to high optical power on the shutter material should be considered and the shutter should be made of an appropriately robust material such as metal.

NOTE 2 In addition to the fibre fuse effect occurring at the connector, this effect can be initiated by contact of the fibre output end with absorbing materials, heating the fibre by arc discharge, formation of bends, knots or crushing.

4.5.2 Contamination particles

Cleanliness of the connectors is very important. Contamination particles at the connector interface can absorb energy and convert it to heat, thus causing the temperature of the fibre to rise above the melting point of silica and failure of the connection. Harmful contaminants are solids such as those produced by wear of alignment sleeves, and also dust and similar particles from the environment. It is suggested that zirconia sleeves be used for higher powers, as these generate a lower level of contamination than metal sleeves.

To avoid these problems, a connector carrying high optical power signals should be as clean as possible. A visual inspection of the ferrule's end-faces before every mating is recommended. This visual inspection should be in accordance with IEC 61300-3-35. When the connectors are demated, a dust cap should be fitted to the ferrules to avoid any contamination. The mating adapter or bulkhead connector should also have a dust cap. The dust caps should be kept clean at all times to prevent cross contamination.

4.6 Degradation or burn-through of dust cap and/or shutter

Dust caps, shutters and similar mechanisms used on connectors should have adequate resistance to burn-through by high power beams. They should be made of material not likely to catch fire or burn through, such as 5V Class material or heat resistant metal with adequate thickness (for example, steel might be a more suitable shutter material than plastic for higher power applications).

4.7 Potentially collimated beam profile resulting in an increased optical hazard

4.7.1 General

In OFCS using higher optical powers, the beam emerging from the fibre may be expanded and/or collimated. Traditionally, the beam emerging from a fibre is a divergent cone, normally resulting in the eye intercepting considerably less power than the total power emerging from the fibre; however, it should still be noted the power may be sufficient to cause injury. One technique for mitigating the hazards to connectors and fibre arising from high optical power densities is to expand and then collimate the beam, thus reducing power density. If the emerging high power beam is collimated in this manner, the protection to people (afforded by diverging beams) may be reduced or even totally lost. Subclause 4.7 addresses issues arising from the use of connectors with inbuilt lenses which produce such a collimated beam.

Other risks may include the use of direct viewing fibre microscopes, which might present a hazard even if an attenuating filter is used in the microscope. However, recent studies have shown that in most cases the use of high magnifying power viewing aids does not increase the hazard. Nevertheless, it is recommended that indirect viewing aids (IVAs) be used to examine high power fibres and components.

4.7.2 High power expanded beam connectors

Even after cleaning, small particles may be overlooked with an inspection microscope, and these could cause the connector to fail. The only way to eliminate this risk is to reduce the power density at the connector interface by enlarging the beam diameter (as discussed above). Typically, expanded beam connectors that use collimating lenses are constructed with rugged bodies suitable for use in harsh environments, and provide high insertion loss values. One method is to use a piece of gradient index fibre (GRIN fibre) instead of an external lens to collimate the beam. This method allows the expanded beam system to be integrated in a standard 2,5 mm or even a 1,25 mm ferrule. The lens will collimate the mode field diameter from, for example, 11 μm to 44 μm (and the beam may be angled at 2° from the fibre axis following angled polishing). If these connectors are opened during operation, the emitted laser beams are often hazardous for a longer distance and over a larger area than those emerging from a normal optical connector with conventional single-mode fibre. It is also possible the hazard at or near this connector is higher than that of the rest of the system.

For example, a calculation of hazard level (HL) 1M for one of these GRIN connectors operating at 1 550 nm results in a HL 1M limit of 14 mW, compared with a limit of 136 mW for the beam emerging from a conventional connector. If the power in the fibre is less than 136 mW and it is fitted with a conventional connector, then it is HL 1M. But if it is fitted with a GRIN connector then for such a system to be HL 1M the power in the fibre would have to be below 14 mW. Also, the beam continues to be dangerous for a much longer distance than is generally expected by telecoms operators used to conventional fibre-to-fibre connectors.

NOTE See also Note 1 in Table D.1 of IEC 60825-2:2004 + AMD1:2006 and AMD2:2010 “Some high power connectors use enlarged mode field diameter (MFD) and the far field divergence is lower. These connectors can result in a higher hazard level and determination of the hazard level when using these connectors is strongly recommended”.

4.8 Increases in the temperatures of attenuators, collimators, splitters and other passive components

Care should be taken that the cleanliness of optical components for use in a high optical power system is not compromised at any time from manufacture to installation. The polished end face of the connector should not be touched or handled, and should be cleaned only with appropriate techniques according to recommended instructions.

Every connection should be checked for cleanliness and/or damage according to IEC 61300-3-35 (with an attenuator to reduce optical power to a safe level for eye viewing in case the fibre is accidentally powered up) or an equivalent indirect viewing aid. It is recommended that connectors, fibre ends prepared for splicing and similar be checked for cleanliness before making a connection or splicing. It is also recommended that these be checked before high power is applied to the system. Materials used for optical components intended for use in high optical power systems, i.e. connectors, attenuators, collimators, shutters, etc. should also have the appropriate flammability rating.

Some optical passive components – for example, plug style optical attenuators using metal-doped fibres, containing optical power absorbing materials – are poorly resistant to high optical powers. According to high power evaluations and thermal simulation, the allowable maximum power to maintain long term reliability for SC type (IEC 61754-4) plug style fixed optical attenuators (10 dB attenuation), is around 300 mW. That maximum power depends on the attenuation value and care should be taken when using high optical powers. Refer to IEC TR 62627-03-03.

Note that damage testing of passive components (e.g. fibre splitters) may be necessary over quite long times at high powers to ensure that the packaging materials (and coatings) do not fail under high power operation.

OFC/NFOEC 2010 JThA60 [13], IEC TR 62627-03-02, OITDA-TP 04/SP-PD-2008 [14] and OITDA-TP 09/SP-PD-2010 also provide useful information. Optical isolators generally contain Faraday rotators which absorb approximately 1 % of optical power.

4.9 Additional labelling

The possible extra hazard due to increased optical powers may result in a need to provide extra labelling and more user information over and above that specified in IEC 60825-2.

It may be necessary to use additional labelling to draw attention to the high optical powers present in the fibre and thus the potential for fibre or connector damage, or damage to the cladding (or even damage to adjacent low power fibres). Extra labelling about potential fire hazards is recommended if the optical power in the fibre exceeds 500 mW. Alternatively, rigorous administrative controls (such as key controlled access to locations where high powers are present) may be used.

As OFCS fibres can be extensive in length, label(s) should be provided at access points, where appropriate.

In addition to the required markings of IEC 60825-2, hazard levels 2, 2M, 3R and 3B locations in a high optical power OFCS should bear the warning label – hazard symbol as shown in Figure 3 of IEC 60825-1:2014.

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