INTERNATIONAL STANDARD

IEC 60825-2

Second edition
2000-05

Safety of laser products –

**Part 2:
Safety of optical fibre communication systems**

Sécurité des appareils à laser –

*Partie 2:
Sécurité des systèmes de télécommunication par fibres optiques*

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Terminology, graphical and letter symbols

For general terminology, readers are referred to IEC 60050: *International Electrotechnical Vocabulary* (IEV).

For graphical symbols, and letter symbols and signs approved by the IEC for general use, readers are referred to publications IEC 60027: *Letter symbols to be used in electrical technology*, IEC 60417: *Graphical symbols for use on equipment. Index, survey and compilation of the single sheets* and IEC 60617: *Graphical symbols for diagrams*.

* See web site address on title page.

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Safety of laser products

Part 2: Safety of optical fibre communication systems

INTERPRETATION SHEET 1

General instruction for all normative clauses, including annex B:

Replace "Hazard Level 2 " *with* "Hazard level 2 or Hazard level 2M, as appropriate".

Replace "Hazard Level 3A" *with* "Hazard Level 1M or Hazard Level 3R, as appropriate".

In Annex B, 3B Hazard Level, controlled location column, replace "Hazard Level kx3A" with "Hazard Level 1M or 2M."

Delete all remaining references to "Hazard Level kx3A".

All classification and hazard level evaluations shall be made in accordance with IEC 60825-1, Amendment 2.

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4.4.2

In table 1, the limiting aperture values for IEC 60825-1, Amendment 2 shall be substituted.

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Annexes

Delete all informative annexes.

Replace old annex B by the following new annex A:

Annex A
(normative)

Summary of engineering requirements at locations in optical fibre communication system

Hazard level	Location type		
	Unrestricted	**Restricted**	**Controlled**
1	No requirements	No requirements	No requirements
1M	1) Labelling, and 2) Class 1* from connector or connector requires tool	Labelling	Labelling
2 and 2M	1) Labelling, and 2) Class 1* from connector, or connector requires tool	Labelling	Labelling
3R	Not permitted **	1) Labelling, and 2) Class 1M* from connector, or connector requires tool	1) Labelling, and 2) class 1M or 2M* from connector or connector requires tool
3B	Not permitted **	Not permitted**	1) Labelling, and 2) Protected cables, and 3) class 1M or 2M* from connector or connector requires tool
4	Not permitted **	Not permitted **	Not permitted**

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

** See 4.4.3. Where systems employ power levels of class 3R or more, protection systems such as APR may be used to obtain the acceptable hazard level for the particular location type.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

SAFETY OF LASER PRODUCTS –

Part 2: Safety of optical fibre communication systems

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of the IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested National Committees.
3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical specifications, technical reports or guides and they are accepted by the National Committees in that sense.
4) In order to promote international unification, IEC National Committees undertake to apply IEC International Standards transparently to the maximum extent possible in their national and regional standards. Any divergence between the IEC Standard and the corresponding national or regional standard shall be clearly indicated in the latter.
5) The IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with one of its standards.
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International Standard IEC 60825-2 has been prepared by IEC technical committee 76: Optical radiation safety and laser equipment.

This second edition cancels and replaces the first edition published in 1993 and amendment 1 (1997). This second edition constitutes a technical revision.

The text of this standard is based on the first edition, amendment 1 and the following documents:

FDIS	Report on voting
76/208/FDIS	76/211/RVD

Full information on the voting for the approval of this standard 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 3.

IEC 60825-2 constitutes part 2 of a series of publications under the general title: Safety of laser products.

Annex B forms an integral part of this standard.

Annexes A, C, D and E are for information only.

The committee has decided that the contents of this publication will remain unchanged until 2003. At this date, the publication will be

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

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

SAFETY OF LASER PRODUCTS –

Part 2: Safety of optical fibre communication systems

1 Scope

This part 2 of IEC 60825 provides requirements and specific guidance for the safe use of optical fibre and/or control communication systems where optical power may be accessible at great distance from the optical source. It does not apply to optical fibre systems primarily designed to transmit optical power for applications such as material processing or medical treatment.

Throughout this part of IEC 60825, light emitting diodes (LEDs) are included whenever the word "laser" is used.

The objective of this part 2 of IEC 60825 is to:

– protect people from optical radiation resulting from optical fibre communication systems. This requires the introduction of engineering requirements and work practices according to the degree of hazard;

– lay down requirements for manufacturers and operating organizations in order to establish procedures and supply information so that proper precautions can be adopted;

– ensure adequate warning to individuals of the hazards associated with optical fibre communication systems through signs, labels and instructions;

– reduce the possibility of injury by minimizing unnecessary accessible radiation, give improved control of the optical radiation through protective features and provide safe usage of products by specifying user control measures.

Annex A gives a more detailed rationale for this part of IEC 60825.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 60825. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of IEC 60825 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60794-2:1989, *Optical fibre cables – Part 2: Product specifications*

IEC 60825-1:1993, S*afety of laser products – Part 1: Equipment classification, requirements and user's guide*

3 Definitions

For the purpose of this part of IEC 60825, the following definitions apply. They are in addition to those given in IEC 60825-1.

3.1
accessible location
any part within an optical fibre communication system at which, under reasonably foreseeable circumstances, human access to laser radiation is possible

3.2
automatic power reduction
feature of an optical fibre communication system 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

3.3
enclosed system
system in which, during normal operation, the optical radiation is totally enclosed, e.g. by light-proof cabinets, components, total internal reflection of optical fibre cables and connectors

3.4
end-user
person/organization using the optical fibre communication system in the manner the system was designed to be used. The user cannot necessarily control the power generated and transmitted within the system

3.5
hazard level
potential hazard at any accessible location within an optical fibre communication system. It is based on the level of optical radiation which could become accessible in reasonably foreseeable circumstances, e.g. a fibre cable break. It is closely related to the laser classification procedure in IEC 60825-1

3.6
hazard level 1
hazard level 1 is allocated to any accessible location within an optical fibre communication system at 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

3.7
hazard level 2
hazard level 2 is allocated to any accessible location within an optical fibre communication system at which, under reasonably foreseeable circumstances, human access to laser radiation in excess of the accessible emission limits of class 2 for the applicable wavelengths and emission duration will not occur

3.8
hazard level 3A
hazard level 3A is allocated to any accessible location within an optical fibre communication system at which, under reasonably foreseeable circumstances, human access to laser radiation in excess of the accessible emission limits of class 3A for the applicable wavelengths and emission duration will not occur

3.9
hazard level $k \times$ 3A
in the wavelength range 400 nm to 4 000 nm, a hazard level $k \times$ 3A is allocated to any accessible location within an optical fibre communication system at which, under reasonably foreseeable circumstances, human access to laser radiation in excess of the accessible emission limits of hazard level $k \times$ 3A for the applicable wavelengths and emission duration will not occur. For purposes of the $k \times$ 3A hazard level evaluation, class 3A AEL table is used; the minimum measurement distance shall be increased to 250 mm from the apparent source and the time base used shall be 10 s, provided longer viewing durations are not reasonably foreseeable. For wavelengths greater than 1 400 mm, the radiant power limit shall be a factor of 10 greater than for class 1

NOTE The value of k is not a constant and need not be calculated (see annex A for rationale).

3.10
hazard level 3B
hazard level 3B is allocated to any accessible location within an optical fibre communication system at which, under reasonably foreseeable circumstances, human access to laser radiation in excess of the accessible emission limits of class 3B for the applicable wavelengths and emission duration will not occur

3.11
hazard level 4
hazard level 4 is allocated to any accessible location within an optical fibre communication system at which, under reasonably foreseeable circumstances, human access to laser radiation in excess of the accessible emission limits of class 3B for the applicable wavelengths and emission duration may occur

3.12
light emitting diode (LED)
any semiconductor p-n junction device which can be made to produce electromagnetic radiation by radiative recombination in the semiconductor, in the wavelength range from 180 nm to 1 mm. (The optical radiation is produced primarily by the process of spontaneous emission, although some stimulated emission may be present.)

3.13
local operator control
an optical communication system is under local operator control if the operating controls and the optical output may be directly monitored simultaneously by a single operator who has control over the potential human access to optical radiation

3.14
location with controlled access
location where access to the protective housing (enclosure) is controlled and is accessible only to authorized persons who have received adequate training in laser safety and the servicing of the system involved. Examples include optical cable ducts and switching centres

3.15
location with restricted access
location where access to the protective housing (enclosure) is restricted and not open to the public. Examples include industrial and commercial premises

3.16
location with unrestricted access
location where access to the protective housing (enclosure) is unrestricted. Examples include domestic premises and premises open to the public

3.17
manufacturer
organization/individual who assembles optical devices and other components in order to construct or modify an optical fibre communication system

3.18
operating organization
organization/individual who is responsible for the installation and/or operation of an optical fibre communication system

3.19
optical fibre communication system
engineered assembly for the generation, transference and reception of optical radiation arising from lasers, in which the transference is by means of optical fibre for communication and/or control purposes

3.20
reasonably foreseeable event
event the occurrence of which under given circumstances can be predicted fairly accurately, and the occurrence probability or frequency of which is not low or very low.

Examples of reasonably foreseeable events might include the following: component failure, fibre cable break, optical connector disconnection, operator error or inattention to safe working practices.

Reckless use or use for completely inappropriate purposes is not to be considered as a reasonably foreseeable event

3.21
protected cable
a cable in which the fibre or fibres are contained within a robust sheath which permits normal handling without breakage and/or exposure of the fibre ends. See also 4.1.2.2 and annex B

3.22
subassembly
any discrete unit of an optical fibre communication system which contains an optical emitter or optical amplifier

4 Manufacturing requirements

4.1 Engineering specifications

4.1.1 General remarks

Optical fibre communication systems require certain built-in safety features, depending on their hazard level. The manufacturer of the optical fibre communication system is responsible for the allocation of the hazard level and for compliance with the manufacturing requirements. These requirements are summarized in annex B.

Whenever alterations which may affect hazard levels are made to the optical fibre communication system, the person or organization performing such a modification shall reassess the hazard levels by carrying out tests and measurements, wherever appropriate, for ensuring compliance and, where the hazard level has changed, relabelling.

Manufacturers of ready-for-use optical fibre communication systems which are to be supplied to end-users are responsible for assessing the hazard levels of the optical system under all reasonably foreseeable circumstances and for compliance with the appropriate manufacturing and safety requirements.

Manufacturers of ready-for-use optical transmission subassemblies which are intended to be used only as part of an OFCS need not classify such equipment but are responsible for assessing the hazard levels of the optical system under all reasonably foreseeable circumstances and for the compliance with the appropriate manufacturing and safety requirements.

For other optical communication systems, the operating organization has the ultimate responsibility for the safety of the system. This includes especially:

– the identification of the location type at all subdivisions of the entire transmission path;
– the assessment of hazard level at any accessible location in the case of reasonably foreseeable events;
– assuring compliance with the manufacturing and safety requirements.

Optical fibre communication systems that also transmit electrical power shall meet the requirements of this standard in addition to any applicable electrical standard.

4.1.2 Cable design

The mechanical design of optical fibre cables shall be specified according to the hazard level and location (see clause D.3 for examples).

If such cables are not at a controlled location:

4.1.2.1 In all systems, the mechanical characteristics of the individual single or multiple fibre cable shall be not less than those required by IEC 60794-2.

4.1.2.2 Locations with hazard levels in excess of 3A shall have the above cable requirements with further and adequate mechanical protection.

4.1.3 Cable connectors

4.1.3.1 All systems operating in unrestricted locations in which cable connectors are accessible require the use of a tool for disconnection if hazard level 1 can be exceeded.

4.1.3.2 All systems operating in restricted locations in which cable connectors are accessible require the use of a tool for disconnection if hazard level 3A can be exceeded.

4.1.3.3 All systems operating in controlled locations in which cable connectors are accessible require the use of a tool for disconnection if hazard level $k \times$ 3A can be exceeded.

4.1.3.4 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.

4.1.4 Automatic power reduction

Automatic power reduction may be used to control the hazard levels defined in 3.6 to 3.11.

4.2 Labelling

4.2.1 Optical fibre cables should carry appropriate markings to distinguish them from cables containing other services, e.g. electricity.

4.2.2 Sleeving, a tag or a tape shall be associated with each optical connector if the hazard level at the location is in excess of hazard level 1. The sleeving, tag or tape shall be coloured yellow, with the warning label according to figure 14 of IEC 60825-1 and the hazard level number incorporated in the explanatory label according to figure 15 of IEC 60825-1, both labels appropriately reduced in size.

4.2.3 Groups of connectors such as patch panels may be labelled as a group, with just a single clearly visible location hazard label rather than having each connector individually labelled. If a group of connectors is enclosed within a box, a label shall be clearly visible both before and after the access panel is opened, which may require the use of more than one label.

4.3 Provision of information

Manufacturers of ready-for-use optical fibre communication systems and manufacturers of ready-for-use subassemblies shall provide the operating organization with the following information, where applicable:

a) an adequate description of the engineering design features incorporated into the product to prevent access to hazardous levels of optical radiation;

b) adequate instructions for proper assembly, maintenance and safe use, including clear warnings concerning the precautions to be taken in order to avoid possible exposure to hazardous radiation;

c) a statement, in SI units, of the power propagating in the fibre at all locations in the system, together with the pulse duration and pulse repetition frequency, or the maximum modulation frequency. The cumulative measurement uncertainty and any expected variation in the measured quantities at any time after manufacture shall also be provided;

d) a statement of the range of operating wavelength(s) within the optical fibre communication system at the time of manufacture and under specified conditions as well as the range of emission wavelengths expected during normal operation at any time after manufacture;

e) the reaction time of any automatic power reduction system;

f) legible reproductions (in appropriate colours or in black and white) of all the labels and hazard warnings to be displayed at locations within an optical fibre communication system or subassembly, as appropriate;

g) a clear indication of all locations of apertures and fibre connectors;

h) a listing of controls, adjustments and procedures for operation and maintenance, including a warning, where appropriate;

i) advice on safe operating procedures, and warnings concerning known malpractices, malfunctions and hazardous failure modes. Where maintenance procedures are detailed, they shall, wherever possible, include explicit instructions on the safe procedures to be followed;

j) where installation or servicing requires that an automatic power reduction system is overridden, information to enable the operating organization to specify a safe system of work at such times, and a safe procedure for the reinstating and safe testing of the automatic power reduction system;

k) any other information relevant to the safe use of the optical fibre communication system or subassembly, as appropriate.

4.4 Assessment of hazard level

4.4.1 The hazard level is determined by the measurement of optical radiation accessible in any reasonably foreseeable event. The methods for the determination of compliance with the specified radiation limit values are the same as those described for classification in IEC 60825-1. Measurements need to be taken under the appropriate conditions, e.g. simulated fibre cable break, and shall be based on the relevant clauses in IEC 60825-1. The assessment of the hazard level shall take place:

– 1 s after the reasonably foreseeable event for unrestricted locations, unless measurement at a later time would result in a larger exposure;

– 3 s after the reasonably foreseeable event for restricted and controlled locations, unless measurement at a later time would result in a larger exposure.

In circumstances where it is difficult to carry out direct measurements, an assessment of hazard level based on calculations may be acceptable. For example, the knowledge of the laser power and fibre attenuation may allow an assessment of the hazard at any particular location.

4.4.2 Additionally, for locations with a hazard level lower than that which would be assigned if no automatic power reduction were employed, the irradiance or radiant exposure during the maximum time to reach the lower hazard level specified in 4.4.1 (1 s for unrestricted, 3 s for restricted or controlled locations) shall not exceed the irradiance or radiant exposure limits (MPE) for the corresponding conditions listed in table 1. The measurement aperture for the MPE at 3 s, for wavelengths greater than or equal to 1 400 nm, shall be 3,5 mm for this subclause only.

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

NOTE The 100 s interval is the time base for classification of invisible infra-red radiation for unintentional viewing.

Table 1 – Assessment of hazard level during shutdown time for systems employing automatic power reduction (see 4.4.2)

Location type	Maximum time to reach lower hazard level (Exposure time basis for 4.4.2)	Limiting aperture		Distance from aperture to fibre
		400 nm to 1 400 nm wavelengths	Other wavelengths	
Unrestricted	1 s	7 mm	1 mm	100 mm
Restricted	3 s	7 mm	3,5 mm	100 mm
Controlled	3 s	7 mm	3,5 mm	250 mm

4.4.3 Tests shall be carried out under reasonably foreseeable fault conditions.

In some complex systems (e.g. 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 annex C).

4.4.4 For optical fibre communication systems with automatic power reduction, the hazard level will be determined by the normal level of power in the fibre and the speed of the automatic power reduction. The speed of power reduction required to obtain a specific hazard level can be determined from the AEL tables in IEC 60825-1. For example, a relatively high optical power level on a fibre together with a high speed automatic power reduction could have the same hazard level as a relatively low optical power on the fibre together with a slower automatic power reduction.

4.5 Requirements for installation

4.5.1 Optical fibre communication systems operating in unrestricted locations shall have a hazard level of 1, 2 or 3A.

4.5.2 Optical fibre communication systems operating in restricted locations shall have a hazard level of 1, 2, 3A or $k \times$ 3A.

4.5.3 Optical fibre communication systems operating in controlled locations shall have a hazard level of 1, 2, 3A, $k \times$ 3A or 3B.

4.5.4 No optical fibre communication system shall have locations with a hazard level of 4.

4.6 Requirements for restart pulses

Restart pulses used after automatic power shutdown shall be limited to hazard level 1 in unrestricted locations, hazard level 3A in restricted locations and hazard level $k \times$ 3A in controlled locations.

5 Guidance for service and maintenance

5.1 Tests and measurements

5.1.1 Tests, measurements and operations in cable ducts and switching centres should be considered as service or maintenance operations. Wherever possible, diagnostic tests should be carried out in such a way as not to increase the hazard level at any location. It may be necessary to have administrative controls which, in some cases, may involve a permit to work system. When connecting test equipment, due regard should be given to establishing the actual power levels introduced into the system in assessing the hazard.

5.1.2 There shall be clearly defined conditions under which automatic power reduction facilities may be overridden.

When overridden, the hazard level shall be reassessed by the operating organization and the appropriate safety precautions described in 5.2 and its associated subclauses shall be taken as appropriate to the reassessed hazard level.

5.1.3 Any viewing optics for fibre examination and splicing should reduce exposure to below the relevant maximum permissible exposure (MPE) and should be approved for use by the operating organization.

5.1.4 Wherever reasonably practical, servicing, maintenance and repair should be carried out with no power propagating in the fibre, otherwise the system should be operated at the lowest power consistent with the need.

5.1.5 The system operating organization shall establish that work practices prevent human exposure to radiation in excess of the relevant MPE.

5.2 Safety precautions

5.2.1 General remarks

5.2.1.1 In locations where, during service or maintenance, radiation levels in excess of class 3A may be encountered (e.g. during switching, in controlled locations), appropriate eye protection should be provided.

5.2.1.2 Before working on any optical fibre cable or system, the staff should check the operating status and hazard level. In the case of systems that are installed and activated, this will be indicated by the appropriate hazard level warning labels. During installation, these labels may not have been provided yet and, in their absence, precautions appropriate to the classification of any test equipment containing optical sources connected to the fibre should be used.

5.2.1.3 During the installation or testing of an optical fibre cable or network, only test equipment of laser class 1, 2 or 3A should be used.

If, in a particular instance, it is essential to use test equipment of a higher class, the accessible fibre ends and connectors at all locations should be secured and labelled with the appropriate hazard level before testing proceeds.

5.2.1.4 Entry points to controlled areas with a hazard level of $k \times$ 3A and above shall have:

– a sign bearing the warning label according to figure 14 in IEC 60825-1 and indicating the hazard level number incorporated in the explanatory label according to figure 15 of IEC 60825-1;
– a sign limiting access to authorized persons only and explaining the existence of a potential hazard.

5.2.1.5 Each person engaged in the installation or service of an optical fibre cable or system should:

– observe all rules, procedures and practices established for the safe operation of optical fibre communication systems;
– immediately notify the supervisor of conditions or practices that have the potential to cause personnel injury or property damage;
– immediately report to the supervisor any known or suspected abnormal exposure to optical radiation.

5.2.2 Precautions in locations with hazard levels greater than hazard level 2

5.2.2.1 Only the staff who have attended an optical fibre safety training course should be permitted to work on optical fibre systems in a location with hazard levels $k \times$ 3A and 3B.

5.2.2.2 The staff should not view directly any energized fibre end or connector end at a location with a hazard level 3A, $k \times$ 3A or 3B. Only viewing aids with appropriate attenuation should be used at a location with a hazard level 3A, $k \times$ 3A or 3B, under all circumstances.

5.2.2.3 Where possible, optical transmission or test equipment should be shut down, put into a low-power state or disconnected before any work is done on exposed fibres, connectors etc. In that case, unintentional switching on should be prevented by a remote control switch or another suitable method. The status of the line (power on or off) should be clearly indicated.

5.2.2.4 The staff should ensure that optical fibre communication systems and test equipment in locations with a hazard level $k \times$ 3A or 3B are properly operated and controlled so as to protect unauthorized personnel.

5.2.3 Training programme

The employer of staff installing or maintaining optical fibre communication systems should establish and maintain an adequate programme for the control of hazards. Safety and training programmes should be instituted for staff working on fibres or communication systems with a hazard level of $k \times$ 3A or 3B. Such programmes should be directed by individuals competent in the field of laser and optical fibre communication system safety. The programmes should provide, as a minimum:

– background information on optical fibre communication systems;
– safety information concerning the laser classification system and hazard levels;
– guidance on the safe use of laser optical fibre communication systems, and adequacy of safety practices.

Annex A
(informative)

Rationale

The safety of laser products, equipment classification, requirements and user's guide are covered by IEC 60825-1. This part is primarily aimed at self-contained products which are under effective local control. An optical fibre communication system would be safe under normal operating conditions because the optical radiation is totally enclosed under intended operation. However, because of the extended nature of these systems (where optical power, under certain conditions, may be accessible many kilometres from the optical source), the precautions to minimize the hazard will be different from those concerning more conventional laser sources which are normally under local operator control. (It should be noted that many optical fibre communication systems contain LEDs, which are included in the scope of IEC 60825-1.)

The potential hazard of an optical fibre communication system depends on the likelihood of the protective housing being breached (e.g. a disconnected fibre connector or a broken cable) and on the nature of the optical radiation that might subsequently become accessible. The engineering requirements and user precautions that are required to minimize the hazard are specified in this part of IEC 60825.

Each accessible location within an optical fibre communication system is allocated, by the system operating organization or his delegate, a hazard level which gives a guide as to the potential hazard if optical radiation becomes accessible. These hazard levels are described as hazard levels 1 to 4, in a fashion similar to the classification procedure described in IEC 60825-1. In addition, a distinction is made between the higher and lower power ranges within the 3B class (see later in this annex for further explanation).

Where operating organizations subcontract parts of a system to installers or manufacturers of subsystems, the duties of all parties concerned should be clearly regulated in an agreement.

In summary, the primary differences between IEC 60825-1 and this part 2 are as follows:

– a whole optical fibre communication system will not be classified in the same way as required by IEC 60825-1. This is because, under intended operation, the optical radiation is totally enclosed, and it can be argued that a rigorous interpretation of IEC 60825-1 would give a class 1 allocation to all systems, which may not reflect the potential hazard accurately. However, if the emitter can be operated separately, it must be classified according to IEC 60825-1;

– each accessible location in the extended enclosed optical transmission system will be designated by a hazard level on similar procedures as those for classification in IEC 60825-1, but this level will be based not on accessible radiation but on radiation that could become accessible under reasonably foreseeable circumstances (e.g. a fibre cable break, a disconnected fibre connector etc.);

– the nature of the safety precautions required for any particular hazard level will depend on the type of location, i.e. domestic premises, industrial areas where there would be limited access, and switching centres where there would be controlled access. For example, it is specified that, in the home, a disconnected fibre connector should only be able to emit radiation corresponding to class 1, whilst, in controlled areas, it could be higher;

– the $k \times$ 3A hazard level was introduced to reflect more realistically the true hazard associated with viewing optical fibre components. The longer measurement distance reflects more common behavioural practices. The shorter time base reflects the fact that it is not normal human behaviour to fixate on a small spot for extended periods of time. Hence, the $k \times$ 3A level allows for increased power levels in optical fibre systems without increasing the risk of ocular damage under reasonably foreseeable circumstances. The value of "k" should not be calculated. The designation $k \times$ 3A is only used to indicate that hazard level $k \times$ 3A is higher than hazard level 3A.

Annex B
(normative)

Summary of engineering requirements at locations in optical fibre communication system

Hazard level	Location type		
	Unrestricted	**Restricted**	**Controlled**
1	No requirements	No requirements	No requirements
2	1) Labelling, and 2) Class 1* from connector, or connector requires tool	Labelling	Labelling
3A	1) Labelling, and 2) Class 1* from connector or connector requires tool	Labelling	Labelling
***k* × 3A**	Not permitted **	1) Labelling, and 2) Protected cables, and 3) Class 3A* from connector, or connector requires tool	Labelling
3B	Not permitted **	Not permitted**	1) Labelling, and 2) Protected cables, and 3) *k* × 3A* from connector or connector requires tool
4	Not permitted **	Not permitted **	Not permitted**
* To be achieved by mechanical design of connector, automatic power reduction or other suitable means. ** See 4.4.3. Where systems employ power levels of class 3A or more, protection systems such as APR may be used to obtain the acceptable hazard level for the particular location type.			

Annex C
(informative)

Methods of hazard/safety analysis

Some 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) failure modes and effects analysis (FMEA);

c) failure modes, effects and criticality analysis (FMECA) (see IEC 60812 [1]*);

d) fault tree analysis (FTA);

e) event tree analysis;

f) hazards and operability studies (HAZOPS);

g) cause-consequence analysis.

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 are to be stated by the manufacturer.

* Figures in square brackets refer to the bibliography.

Annex D
(informative)

Application notes for the safe use of optical fibre communication systems

D.1 Introduction

This annex provides guidance on the application of this standard to specific practical situations. It applies to optical fibre communication systems where optical power is normally confined in a fibre and may be accessible at a great distance from the optical source. It does not apply to optical fibre systems primarily designed to transmit optical power for applications such as material processing or medical treatment.

This annex is an informative annex to assist OFCS operators in applying the requirements of IEC 60825-1 and IEC 60825-2 to their specific application. It does not contain any manufacturer or installer requirements.

D.2 Definitions

For the purpose of this annex D, the following definitions apply.

D.2.1
FITs
an indicator of reliability defined as the number of failures per 10^9 h

D.2.2
HITs
the number of hazard incidents per 10^9 h

D.3 Areas of application

D.3.1 Typical optical fibre installations

a) Locations with controlled access (see 3.14):
   - cable ducts
   - street cabinets
   - manholes
   - dedicated and delimited areas of network operator distribution centres
   - test rooms in cable ships
   - buried and submerged cables
b) Locations with restricted access (see 3.15):
   - secured areas within industrial premises not open to the public
   - secured areas within business/commercial premises not open to the public (for example telephone PABX rooms, computer system rooms, etc.)
   - general areas within switching centres
   - delimited areas not open to the public on trains, ships or other vehicles
   - overhead fibre optic cables and cable drops to a building
   - optical test sets

c) Locations with unrestricted access (see 3.16):
   – domestic premises
   – industrial commercial or business premises (e.g. offices)
   – public areas on trains, ships or other vehicles
   – open public areas such as parks, streets, etc.

Distributed fibre networks may pass through unrestricted public areas (for example in the home), restricted areas within industrial premises, as well as controlled areas such as cables ducts or street cabinets.

OFCS local area networks (LANs) may be deployed entirely within restricted business premises.

Fibre systems may be entirely in unrestricted domestic premises such as hi-fi interconnections.

Infra-red (IR) wireless LANs are outside the scope of this annex.

D.3.2 Typical hardware components

a) Fibre cables: single/multiple/ribbon construction
   single/multimode
   carrying single/multiple wavelengths
   uni/bidirectional, fibre
   communications/power feeding
b) Optical sources: LEDs, communications lasers, pump lasers, optical amplifiers
   bulk/distributed, continuous/low/high-frequency emission
c) Connectors: permanent/semi-permanent, single/multiple
d) Power splitters, wavelength demultiplexers, attenuator
e) Enclosures and protective housings
f) Fibre distribution frames.

D.3.3 Typical conditions

a) Installation
b) Operation
c) Maintenance
d) Servicing
e) Fault
f) Measurement (including optical time domain reflectometry (OTDR))

D.4 Optical fibre power system limits

Mean power fibre limits for the laser classes are presented below at various wavelengths in the optical fibre. For most typical systems with duty cycles between 10 % and 100 %, the peak power can be allowed to increase as the duty cycle decreases. However, for duty cycles ≤50 %, it is most straightforward to limit the peak powers to twice these mean power limits, although IEC 60825-1 can be used for a more sophisticated analysis in order to identify any increase in peak powers permissible for these types of systems.

D.5 Hazard level evaluation examples

NOTE For optical sources, enclosures and protective housings already classified according to IEC 60825-1 by the manufacturer, the hazard level according to IEC 60825-2 may be different from the classification according to IEC 60825-1. The reasons for these differences are:

– IEC 60825-2 has a hazard level $k \times$ 3A for restricted and controlled access situations;

– the operator uses automatic power reduction (APR) for the determination of the hazard level;

– results from fault analysis in IEC 60825-2 may be different from single fault analysis in IEC 60825-1.

D.5.1 Multiple wavelengths over the same fibre

When more than one wavelength is used on the same fibre, such as on a wavelength division multiplex system (WDM), then the hazard level depends on both the power levels and on whether the wavelengths are additive. For skin exposure to wavelengths usually used in optical fibre communication systems, the hazards are always additive. For most fibre systems, 1 400 nm is the point at which addition conditions change:

a) if two wavelengths are both below 1 400 nm, they add, i.e. the combined hazard is higher;

b) if two wavelengths are both above 1 400 nm, they add, i.e. the combined hazard is higher;

c) if one wavelength is above 1 400 nm and one is below, then retinal hazards do not add, i.e. the combined hazard does not increase.

It is necessary to calculate separately for skin and retinal hazards. To calculate the combined hazard level in a multi-wavelength system, it is necessary to calculate the system power at each wavelength as a proportion of the AEL for that class at that wavelength (for example 25 %, 60 %, etc., up to 100 %), and add together. If the totalled proportion exceeds 1 (100 %), then the hazard level exceeds that class.

Multi-wavelength example

An optical transmission system using multimode fibre of 50 µm core diameter and a numerical aperture 0,2 ± 0,02 carries six optical signals: at wavelengths of 840 nm, 870 nm, 1 290 nm, 1 300 nm, 1 310 nm and 1 320 nm. Each of these signals has a maximum time-averaged power of –8 dBm (0,16 mW). Determine the location hazard level at the transmitter site.

In the absence of any other information concerning the transmitter emission duration when a connector is removed, assume that no shut-down system operates, and classify on the basis of the power levels accessible at the transmitter connector (removing the connector is a reasonably foreseeable event).

Assess on the basis of:

– 100 s emission duration (see 9.3 e) of IEC 60825-1), and

– a minimum viewing distance of 100 mm (see 8.2 c) of IEC 60825-1).

Table 5 of IEC 60825-1 indicates that the effects of all wavelengths are additive. The evaluation must therefore be made on the basis of the ratio of the accessible emission at each wavelength to the AEL for the laser class at that wavelength (see 9.3 b) of IEC 60825-1).

Note, however, that the AELs are constant in the wavelength range 1 200 nm to 1 400 nm; hence, the four signals in the vicinity of 1 300 nm may be considered as a single signal with a power level equal to the sum of powers in those signals.

First compare the emission levels with the AEL for class 1:

$$\mathrm{AEL}_{840\ \mathrm{nm\ or}\ 870\ \mathrm{nm}} = 7 \times 10^{-4} t^{0,75} \mathrm{C}_4 \mathrm{C}_6\ \mathrm{J}$$

$$= 7 \times 10^{-4} t^{-0,25} \mathrm{C}_4 \mathrm{C}_6\ \mathrm{W}$$

where $\mathrm{C}_4 = 10^{0,002(\lambda - 700)}$

and, for a point source, $\mathrm{C}_6 = 1$

$$\mathrm{AEL}_{1\ 300\ \mathrm{nm}} = 3,5 \times 10^{-3} t^{0,75} \mathrm{C}_6 \mathrm{C}_7\ \mathrm{J} = 3,5 \times 10^{-3}\ t^{-0,25}\ \mathrm{C}_6 \mathrm{C}_7\ \mathrm{W}$$

where $\mathrm{C}_7 = 8$

hence $\mathrm{AEL}_{840\ \mathrm{nm}}$ = 0,42 mW

$\mathrm{AEL}_{870\ \mathrm{nm}}$ = 0,49 mW

$\mathrm{AEL}_{1\ 300\ \mathrm{nm}}$ = 8,9 mW

Using the expression for the diameter of the beam from an optical fibre (equation (1) in A.6 of IEC 60825-1), the diameter at the 63 % (1/e) points for the smallest NA fibre (worst case) is:

$$d_{63} = \frac{2r\ \mathrm{NA}}{1,7} = \frac{2 \times 100 \times 0,18}{1,7} = 21,2\ \mathrm{mm}$$

The fraction of the beam that would pass through the 50 mm aperture specified in the measurement conditions is therefore (using equation (3) of example A.6 of IEC 60825-1):

$$\eta = 1 - \exp(-[d_a/d_{63}]^2) = 0,99$$

Thus, in this case, all of the fibre power would be collected by the 50 mm aperture, and no correction is needed.

Summing the ratios of the power at each wavelength to the corresponding AEL yields:

$$\sum \left[\frac{(\mathrm{Power})}{\mathrm{AEL}} \right] = \frac{0,16}{0,42} + \frac{0,16}{0,49} + \frac{4 \times 0,16}{8,9} = 0,78$$

This ratio is less than 1; thus, the accessible emission is within class 1 limits and a location hazard level 1 applies.

D.5.2 Bi-directional (full duplex) transmission

There is no additive effect from each separate direction of transmission, as each broken fibre cable end represents a separate hazard if the fibre breaks. The hazard level is determined by the transmission direction with the higher power.

D.5.3 Automatic power reduction

Automatic power reduction is an available option for optical fibre communication systems in order to classify an end-to-end 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. See annex B.

Following the indications of this standard, assessment of the hazard level shall take place at the time of reasonably foreseeable human access to radiation (for example after a fibre break), unless measurement at a later time would result in a larger exposure (see 4.4.1). This could be almost instantaneously after an unprotected fibre splice, after approximately 1 s after a fibre connector disconnect or after several hours, as in the time it takes for a ship to pull up a broken cable from the bottom of the ocean.

Automatic power reduction should not take the place of good work practices and proper servicing and maintenance. Also, the reliability of the APR mechanism shall be taken into account when assessing the hazard level.

Automatic power reduction cannot be regarded as a universally protective measure because, after a fibre break, it is common practice to use an optical test set (usually an optical time domain reflectometer, OTDR) to determine the location of the break. This instrument launches laser power down the fibre under test. Therefore, even if the normal telecommunications transmitter is shut down or removed, the diagnostic tools may impart laser power at a later time.

These OTDRs typically operate at class 1, so no potential hazard is present. However, higher power may require class 3A or class 3B OTDRs to detect the break. Also, OTDR signals may be amplified to a higher class if sent through an optically amplified system.

It is also important that the laser safety professionals or the OFCS operator consider the hazard level under which it is desirable to work. Hazard level 3A or $k \times$ 3A is often cited because workers would be trained not to use any optical (collimating) instruments that would increase the hazard and typically they would have no need to examine the fibre at a close range. Hazard level 3B is acceptable in controlled environments with proper labelling and connector conditions.

This subclause will examine APR under several circumstances:

– on a readily accessible fibre in a splice tray;
– at a fibre optic connector;
– on a fibre not readily accessible in a submerged/buried cable;
– in restricted and unrestricted environments;
– in the case of ribbon cables.

For the tables in this annex, the following upper limit powers are calculated for the typical wavelengths using worst case singlemode fibre (see clause D.4):

1 300 nm:	hazard level 1	=	8,85 mW
	hazard level 3A	=	24 mW
	hazard level $k \times$ 3A	=	83 mW
	hazard level 3B	=	500 mW
1 550 nm:	hazard level 1	=	10 mW
	hazard level 3A	=	50 mW
	hazard level $k \times$ 3A	=	54 mW
	hazard level 3B	=	500 mW

D.5.3.1 Fibre in a splice tray

As powers increase in an OFCS, it is important that splicing operations on potentially energized fibres of hazard level 3B or greater powers take into consideration the safety of the operator, and a fully enclosed splicing system should be employed. If splicing is not to take place in a protective enclosure, automatic power reduction is an option for reducing the hazard level and, therefore, the exposure. Because accessibility to the cut fibre is immediate, power reduction should also be immediate. Table D.2 outlines some timing requirements at typical wavelengths.

D.5.3.2 Connectorized systems

Another area where access to energized fibre is reasonably foreseeable is when an energized system has one or several of its fibres disconnected at an optical connector. A possible and likely assumption that could be made is that human accessibility to the energized fibre would not occur until 1 s after the disconnection. As a result, the power reduction durations specified in table D.2 would be increased by 1 s for this application.

However, an alternative that would result in a safer hazard classification for the transmission equipment itself would be the use of shuttered connectors. These connectors, provided they meet the reliability characteristics outlined in clause D.6, could be a mechanical solution that could be implemented at any connector point along the OFCS. Such a solution would be desirable for controlling exposures from unmated connectors. These shutters should operate within the time restrictions indicated in the previous paragraph. (It should be noted that shutters may not be practical or desirable for controlling hazard level 4 and some higher 3B conditions. In these situations, APR may be the only solution.)

D.5.3.3 Submerged/buried cable for undersea systems

Certain undersea systems have the potential to carry substantial optical power levels. Typically, damage to fibre cable is incurred on the submerged portion, not on the buried land portion. Because the fibre cable is submerged, an appropriate shipping vessel is necessary to retrieve the cable and repair it, which may take hours or days to accomplish. As automatic power reduction may not be appropriate or practical for these systems, rigorous administrative controls, including manual laser shutdown procedures, may need to be employed. This will ensure that proper working conditions are maintained below hazard level 4, as specified in this standard.

Manual shutdown of the system under repair/maintenance/service conditions is currently the practice for many operators because of the hazardous electrical power associated with the submerged cable. This electrical power is used to power the undersea repeaters along the route. In the future, for repeaterless systems, this electrical power may no longer be a part of the cable. However, the work practice to de-energize fibre before extraction must be continued and maintained because of the hazards of the associated laser power.

D.5.3.4 APR for restricted and unrestricted environments

An OFCS that reaches into restricted and unrestricted environments typically contains laser or LED powers in the safer class 1 or class 3A hazard level ranges. Therefore, automatic power reduction methods are less likely to be required for hazard level control. See annex B for other requirements. However, OFCS designers shall be aware of the restrictions in annex B regarding restricted and unrestricted environments, and incorporate APR into any system that has the potential to expose humans to laser or LED power of class 3B (class 3A for unrestricted) and above, in these respective environments. Appropriate reliability precautions shall be taken when designing this power down system.

D.5.3.5 APR for ribbon cables

The use of ribbon cables can place the OFCS on a more restrictive hazard level. A careful hazard assessment, as explained in D.5.5, should take place, and appropriate APR, shuttering and splicing considerations should be evaluated and implemented with respect to the potentially increased hazard level and the environment of the OFCS.

D.5.4 Multiple fibres

The hazard from bundles of broken (i.e. not cleaved) fibre within a broken fibre cable does not increase beyond that of the worst case fibre within that cable. This has been shown by a considerable number of measurements on broken fibre ends, consideration of reflection and scattering at fibre ends, and random alignment and movement of fibre ends.

These measurements and considerations have also been shown to apply to broken ribbon fibre, but not to ribbon fibre cleaved as a unit (see D.5.5).

D.5.5 Ribbon cable

Ribbon fibre ends cleaved as a unit will exhibit a higher hazard level than that of a single fibre. An example would be eight fibres within a ribbon, each carrying a power level just within class 3A. Individually, they are of a relatively safe class 3A hazard level, but cleaved as an unseparated unit, the hazard level becomes class 3B, thus presenting a genuine eye risk. This results from the small centre-centre separation distances of typical ribbon fibre of 150 µm to 250 µm. The low angular separation of several equally spaced fibres leads to a cumulative effect. At the measurement distance of 100 mm, the α of one singlemode fibre is $\ll \alpha_{min}$ for cw emission (for $t > 10$ s, $\alpha_{min} = 11$ mrad, (see 9.3 d) of IEC 60825-1).

The angular subtense of the ribbon in its plane will depend on the number of fibres and their separation (for example an eight-fibre ribbon with fibres spaced at 200 microns will subtend 14 mrad at 100 mm). If this subtense does not exceed α_{min}, the ribbon is considered as a point source. If the angular subtense in the ribbon plane is greater than α_{min}, then the ribbon may need to be treated as an extended source. Any angular dimension that is more than α_{max} or less than 1,5 mrad should be limited to α_{max} or 1,5 mrad respectively before determining the mean.

The total power permitted in the ribbon fibre is then the appropriate (point source or extended source) AEL and, in general, this would be divided equally between all fibres in the ribbon. IEC 60825-1 can be used for a more sophisticated analysis in order to identify any increase in peak powers permissible for ribbon cable arrays.

Ribbon fibre example calculation

<u>Example of calculation:</u>

The ribbon consists of eight equally spaced singlemode fibres. What is the maximum allowed class 1 cw output power per fibre for a wavelength of a) 1 300 nm and b) 1 500 nm?

Solution for a)

The AEL value determines the summed emission for all eight fibres. The 8,85 mW has to be divided by the number of emitters, which leads to a maximum allowed power of 1,1 mW per fibre.

Solution for b)

At 1 550 nm, the hazard for the cornea dominates. Consequently, there is no correction factor C6. The maximum power per fibre is simply the corresponding AEL for one source, divided by the number of fibres, i.e. 10 mW/8 = 1,25 mW.

Ribbon fibre issues

The additive property of the radiation hazard from ribbon fibre sources, therefore, means that the hazard level of a location can depend on the choice of cable type. As it may be impractical to be forced to switch off essential systems if they are designed for live maintenance, a solution will probably be required for reducing the hazard if ribbon fibres are to be used in fibre networks.

The solution may not be too difficult. As broken ribbon fibres do not present a problem, it is only the cleaving and splicing operations that require consideration. Separated ribbon, being no different from normal fibre, also does not present a problem.

If access to unseparated cleaved fibre end can be assuredly prevented, then, as the hazard level relates to ACCESSIBLE emission limits, the hazard level may be prevented from increasing. Any method would have to prevent access under reasonably foreseeable circumstances (i.e. not just an instruction "not to look"!). A possibility might be to use a cleaving tool that stayed attached to the cleaved fibre end until it was inserted into a ribbon splicer that likewise prevented access during the whole operation.

Once ribbon fibre is used in the network, it will be difficult to control what type of system is put onto it.

D.5.6 Power diminution due to power splitters and fibre losses

This power diminution may be taken into account, for example at the customer side of a distribution network, the hazard level after some length of fibre may be lower than at the distribution point.

Figure D.1 shows the layout of a typical passive optical network (PON).

D.5.7 General considerations and examples

a) The assessment of hazard levels shall always consider worst case conditions, including reasonably foreseeable fault conditions (see 4.4.3). Consequently, it may be necessary to include multiple fault conditions, the probability of which shall be judged by the responsible organization.

   NOTE Whereas IEC 60825-1 refers to single fault conditions, it may be reasonably foreseeable that more than one fault will combine to cause a dangerous situation.

b) Service conditions often result in higher hazard levels (see clause 5). These shall be considered by the responsible organization and persons. Examples are: introduction of high power or amplified OTDR pulses into an operating fibre network; failure or overriding of the APR (see 4.3 j)); system restart pulses.

c) Changing of components, system parameters or of the network structure may result in changed hazard levels. Examples are: replacement of conventional bundled fibre cables by ribbon cables (this may be beyond the direct supervision of the network manager); change of the modulation scheme; change in transmitter circuit pack power or wavelength; addition/change of optical amplifiers, etc.

D.6 Fault analysis

Fault analysis is essential for systems where the optical output is dependent on the integrity of other components and the performance of the circuit design. If the chosen method of fault analysis is FMECA, then for hazard levels 1 and 3A systems, the probability of exceeding the class 3A accessible emission limits (under reasonably foreseeable circumstances) should not exceed 500 FITs. It is recommended that the manufacturer or operator should carry out a fault analysis.

Explanation and guidance

Fault analysis

The purpose of fault analysis is to identify failures in the optical control circuits that could have significant consequences affecting the safety classification. The lasers used in hazard level 3A systems may have the capability of emitting power levels in excess of the maximum hazard level 3A AEL limit. However, under normal operation, they operate within the hazard level 3A limit. A fault in a component in the laser drive circuit may increase the power emitted by the laser such that it exceeds the maximum permitted for its assigned classification. Thus, a hazard level 3A system may become hazard level 3B under fault conditions.

Fault probability levels

No system is 100 % fail-safe since there is always a non-zero probability that failures will occur. To quantify the risk of exposure to hazardous radiation, all laser drive circuits should be subject to fault analysis using recognized techniques. Fault analysis carried out on laser drive circuit designs demonstrate that a figure of less than 500 FITs is achievable. On the basis of this figure and the estimated amount of time an engineer works on live fibres throughout his working life, the incident rate for the risk of injury to the eye is less than five HITs. (For example in the UK, the Health and Safety Executive considers an occupational risk of less than 5,43 HITs for accidents to be trivial.)

Commonly used fault analysis techniques

Two commonly used fault analysis techniques are:

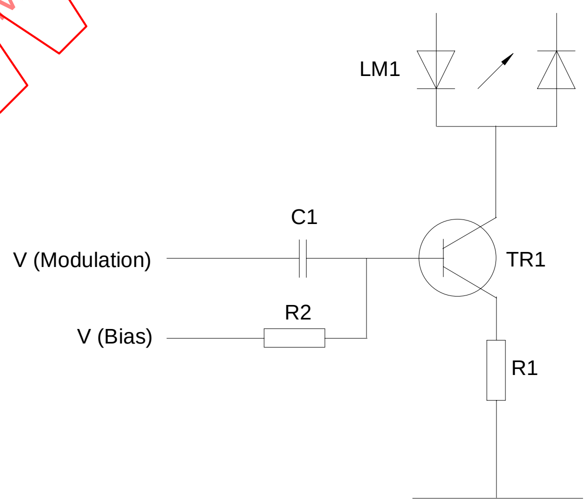
– tests under reasonably foreseeable fault conditions, and
– failure modes effects and criticality analysis (FMECA).

IEC 60812 gives guidance on the use of this technique.

Example of FMECA analysis for circuits

The purpose of the analysis is to provide a quantitative measure of the probability of the optical power exceeding class 3A AEL. The following example illustrates one recommended method.

Consider the simple circuit below.



IEC 542/2000

Step 1: identify critical components

From circuit diagrams and parts lists, identify all the components likely to affect the laser module. Typically, these include mean power control circuitry, data modulator and threshold bias generator. Include automatic power reduction (APR) circuits in the analysis if the function of the APR is to achieve the intended classification, or if an APR component failure could cause a significant increase in the accessible power.

Step 2: identify component failure modes

Construct a table listing the components, their circuit identifier and their most likely failure modes as shown in the example below.

Circuit ID	Component	Failure mode	Beta	Comments
LM1	Uncooled laser	Increase in output Decrease in output No output		
TR1	BFR 96 Mullard <500 mW NPN	Short circuit Open circuit		
R1	47R 2 % 0,25 W	Short circuit Open circuit Parameter drift		
R2	3K9 2 % 0,25 W	Short circuit Open circuit Parameter drift		
C1	0,47 µF 10 % 50 V	Short circuit Open circuit Parameter drift		

The US Department of Defense Reliability Analysis Center (RAC) publication [2] gives a list of likely failure modes. Include a column for comments and request an explanation of the likely outcome of the failure from the engineers consulted (see step 3).

Step 3: determine beta values

Circuit designers or repair engineers are the best people to consult for this task, since it requires a knowledge of how each component operates in the circuit.

Beta values depend on the criticality of the failure mode. A simple analysis assigns a probability figure to the beta value by considering just three categories.

Does the failure mode cause the laser power to exceed class 3A AEL?	Beta value
Yes	1
No	0
Maybe	0,5

The consulted engineers may be able to give better estimates for the beta values.

It is good practice to simulate fault conditions whenever possible.

Step 4: determine failure rates

The next step is to determine base failure rates for each component and apportion failure rates to failure modes. This information is available from two sources:

– the BT Handbook of Reliability Data, HRD5 [3], provides intrinsic failure rates for generic component types at the upper 60 % confidence limit;

– the RAC [2] publication lists the apportionment of failure rates to failure modes.

For example, HRD5 lists the base failure rate (λ_{base}) for a silicon small signal bipolar transistor as eight FITs, and the RAC publication lists the apportionment of failure modes (α) as 73 % for short circuits and 27 % for open circuits. Insert the values into the appropriate columns in the spreadsheet.

Determine the system failure rate by multiplying the columns horizontally and then add vertically. The overall failure rate represents the probability of the system exceeding the intended classification. This is illustrated in the following table.

Circuit ID	**Component**	**Failure mode**	**Beta**	λ_{base}	α	**Product**	**Comments**
LM1	Uncooled laser	Increase in output	1	500	0,05	25,0	May result from fibre movement
		Decrease in output	0	500	0,65	0	
		No output	0	500	0,30	0	Chip failure
TR1	BFR 96 Mullard	Short circuit	1	8	0,73	5,84	I_{laser} limited by R1 (may still be safe, see below)
	<500 mW NPN	Open circuit	0	8	0,27	0	
R1	47R 2 %	Short circuit	1	0,2	0,05	0,01	
	0,25 W	Open circuit	0	0,2	0,84	0	
		Parameter drift	0,5	0,2	0,11	0,01	
R2	3K9 2 %	Short circuit	1	0,2	0,05	0,01	
	0,25 W	Open circuit	0	0,2	0,84	0	
		Parameter drift	0,5	0,2	0,11	0,01	
C1	0,47 µF	Short circuit	1	0,3	0,49	0,15	
	10 % 50 V	Open circuit	0	0,3	0,29	0	
		Parameter drift	0,5	0,3	0,22	0,03	
						Overall failure rate =	31,06 FITs

In this example (assuming 5 V power rail), the maximum laser current is limited by R1 to about 35 mA. This is unlikely to result in a 1,5 µm laser exceeding the class 3A limit. In other cases, this is not always applicable, and reference shall be made to the laser data sheet and individual component values.

In similar examples, where a component failure is significant only if accompanied by simultaneous independent failures in other components, a simple summation of FITs for these components may not be appropriate. In such cases, the failure rate should be calculated from the product of the failure rates of the components concerned.

D.7 Suggested working practices

The following working practices may be regarded as good practice, and are recommended when working with any optical fibre system. Different working practices may apply in different circumstances.

D.7.1 General working practices

The following working practices may be regarded as good practice, or as essential, when working on any optical fibre system:

Viewing fibre	Do not stare with unprotected eyes or with any unapproved collimating device at the fibre ends or connector faces, or point them at other people.
Viewing aids	Use only approved filtered or attenuating viewing aids.
Fibre ends (single or multiple)	Any single or multiple fibre end(s) found not to be terminated (for example, matched, spliced) shall be individually or collectively covered when not being worked on. They shall not be readily visible and sharp ends shall not be exposed. Suitable methods for covering include the use of a splice protector or tape. Always attach end caps to unmated connectors.
Ribbon fibres	Do not cleave ribbon fibres as an unseparated ribbon, or use ribbon splicers, unless authorized.
Test cords	When using optical test cords, the optical power source shall be the last to be connected and the first to be disconnected.
Fibre off-cuts	Collect all fibre off-cuts and dispose of them in an approved container. The container itself should be disposed of in an approved manner.
Maintenance	Follow only approved instructions for operating and maintaining the system being worked on.
Cleaning	Use only approved methods for cleaning and preparing optical fibres and optical connectors.
Modification	Do not make any unauthorized modifications to any optical fibre system or associated equipment.
Board extenders	Board extenders shall not be used on optical transmitter cards. Do not power optical sources when they are outside transmitter racks.
Label damage	Report damaged or missing optical safety labels to line management.
Key control	For equipment with key control, the keys shall be placed under the control of a person appointed by management who shall ensure their safe use, storage and overall control. Spare keys shall be retained under strict control procedures by a nominated line manager.
Test equipment	Use test equipment of the lowest class necessary and practical for the task. Do not use test equipment of a higher class than the location hazard level.
Signs	Area warning signs are required for locations exceeding hazard level 3A. Area signs may be displayed in locations of lower classification.

D.7.2 Live working practices for hazard levels 1, 2, and 3A systems and locations

Live working is permitted using the working practices listed in D.7.1.

D.7.3 Live working practices for hazard level $k \times$ 3A locations and systems

Some telecommunications organizations do not permit live working on hazard level $k \times$ 3A locations or systems.

All of the working practices listed in D.7.1 should be applied.

Warning signs should be erected/displayed, even at temporary work locations.

Use only approved viewing aids with valid calibration labels or test reports.

D.7.4 Working practices for hazard level 3B systems and locations

Responsible and adequate OFCS safety and training programmes should be established and maintained by management. Personnel engaged in the installation and servicing of OFCS should observe all rules, and report to management any potentially unsafe conditions or abnormal exposures to optical radiation.

Live working on hazard level 3B locations or systems is not recommended.

If live working is not permitted on hazard level 3B systems, then the following working practices should be used:

– all general practices defined in D.7.1;

– power down the system (as detailed in D.7.5);

– check that there is no optical power in the fibre using an approved optical power meter;

– cover the ends of all exposed fibres not being worked on. Always attach end caps to unmated connectors;

– use only indirect viewing aids (for example televised or shadow imaging splicing machines). Do not use microscopes without authorization;

– when using optical test cords, the optical power source shall be the last to be connected and the first to be disconnected.

D.7.5 Formal power-down and power-up procedure for hazard level 3B systems and locations

When powering down an optical fibre system (if live working is not permitted), the following procedure shall be adopted.

a) A nominated person at an optical power source shall:
   - have been trained to an appropriate level on the type of equipment which has to be switched on and off;
   - be conversant with the instructions and safety requirements relating to the previous paragraph and with any additional local instructions and circumstances;
   - have a responsible attitude to safety.

b) Nominated persons shall be appointed by line management and be notified of their appointment.

c) A list of nominated persons at each installation shall be recorded and prominently displayed.

d) Before starting work, the person authorized to carry out the work (the originator) shall:
   - contact a nominated person at the appropriate optical power source and request that the power on the relevant fibres be switched off;
   - on duplex systems, a nominated person shall be contacted at each end;
   - on being informed that the power has been switched off, complete the necessary forms which shall be retained by the originator. These forms need not be completed if the originator and the nominated person are one and the same;
   - verify (with a live fibre identifier or optical power meter) that the power is off;
   - on completion of the work, inform a nominated person at the appropriate optical power source(s).

e) On receipt of a request from an originator to switch off an optical power source, the nominated person shall:
   - record the time and date of the request and the details of the originator. Forms shall be kept on file at the location of the optical source;
   - switch off the appropriate power source (with key control, if fitted);

– complete the warning label and affix it to the appropriate station equipment at the point of disconnection, for example equipment rack, distribution frame, be attached for each originator;

– contact the originator and give him the job number and the time that the source was switched off;

– on being informed that the work has been completed, record the details appropriately and remove the warning label from the equipment before re-energizing the source. When more than one originator requires the same power source to be switched off, the source shall not be re-energized before all work is completed.

Table D.1 – Optical fibre system power limits for 11 microns singlemode and 0,18 numerical aperture multimode fibres

	Class 1	Class 2	Class 3A Singlemode	Class 3A Multimode	*k* × 3A Singlemode	*k* × 3A Multimode	Class 3B
633 nm	0,22 mW (–6,6 dBm)	1 mW (0 dBm)		5 mW (+7 dBm)		8,5 mW (+9,3 dBm)	500 mW (+27 dBm)
780 nm	0,32 mW (–4,9 dBm)			1,6 mW (+2 dBm)		4,8 mW (+6,8 dBm)	500 mW (+27 dBm)
850 nm	0,44 mW (–3,6 dBm)			2,2 mW (+3,4 dBm)		6,6 mW (+8,2 dBm)	500 mW (+27 dBm)
980 nm	0,81 mW (–1 dBm)		1,5 mW (+1,8 dBm)	4 mW (+6 dBm)	7,15 mW (+8,5 dBm)	12 mW (+10,9 dBm)	500 mW (+27 dBm)
1 300 nm	8,85 mW (+9,5 dBm)		24 mW (+13,8 dBm)	46 mW (+16,6 dBm)	83 mW (+19,2 dBm)	137 mW (+21,4 dBm)	500 mW (+27 dBm)
1 550 nm	10 mW (+10 dBm)		50 mW (+17 dBm)	50 mW (+17 dBm)	54 mW (+17,3 dBm)	85 mW (+19,3 dBm)	500 mW (+27 dBm)

NOTE 1 **Class 3A 980 nm and 1 300 nm**

The maximum power shown in the table for 11 microns fibre is limited for class 3A at 980 nm and 1 300 nm by the power density AEL rather than the power AEL. The precise fibre power limit is therefore determined by the minimum expected beam divergence, which is in turn dependent on the singlemode fibre mode field diameter (MFD). This may change for different values of the MFD and there are significant changes in class limits as the MFD changes.

NOTE 2 **1 300 nm figures**

The 1 300 nm figures are calculated for 1 270 nm, which is the shortest wavelength in the "1 300 nm" telecommunications window.

NOTE 3 **Fibre parameters**

The fibre parameters used are the most conservative cases; singlemode figures are calculated for a fibre of 11 microns mode field diameter, and multimode figures for a fibre with a numerical aperture of 0,18. Many systems operating at 980 nm and 1 550 nm use fibres with smaller MFDs. For example, at 1 550 nm dispersion shifted fibre cables having upper limit values of MFD of 9,1 microns will have respective limits of 50 mW and 61,2 mW for class 3A and class *k* × 3A.

For other MFD values and wavelengths, please refer to IEC 60825-1, example A.6.3.

NOTE 4 ***k* × 3A**

At 980 nm and 1 300 nm and 10 s, the increased measurement distance of 250 mm results in the power AEL being the more limiting. For 1 550 nm, the power AEL still limits at 250 mm, with no increase for a 10 s time base.

NOTE 5 **Class 3A limits for <1 300 nm**

The class 3A limits for singlemode fibres at 900 nm and below are not presented here, as the divergence that these wavelengths will undergo is rather variable. This is because these wavelengths are in fact multimoded in standard 1 300 nm singlemode fibre, and the exact divergence will depend on the rather unpredictable degree of mode mixing. This mode mixing variability is also a potential problem when trying to evaluate these wavelengths on true multimode fibre. If it is necessary to calculate a value for these cases, the assumption that the fibre carries all of its power in the fundamental mode and use of the singlemode equations will yield a conservative value.

Table D.2 gives example values of the time allowed to reduce optical power from the indicated level to the indicated hazard level. The figures of this table are calculated for a singlemode fibre of 11 microns mode field diameter. The 1 300 nm figures are calculated for 1 270 nm.

The values of the time specified in the table are calculated by the following equation:

$$P\ t = Q(t)$$

where

t is the time to be calculated;

P is the indicated emission power;

Q(*t*) is the maximum emission energy compatible with the indicated hazard level for an emission duration equal to *t*;

Q(*t*) is a function of *t* obtained by the appropriate AEL. It is also necessary to take into account the fraction of beam that would pass through the applicable limiting aperture.

Table D.2 – Automatic power reduction – Immediately accessible situations

1 300 nm			Equation code
31 mW to $k \times$ 3A: N/A	100 mW to $k \times$ 3A: 4,8 s	250 mW to $k \times$ 3A: 0,12 s	1
31 mW to 3A: 36 s	100 mW to 3A: 0,33 s	250 mW to 3A: 0,0085 s	2
31 mW to 1: 0,67 s	100 mW to 1: 0,0062 s	250 mW to 1: 0,00016 s	1
1 550 nm			
		550 mW to 3B: 0,23 s	1
100 mW to $k \times$ 3A: 0,44 s	250 mW to $k \times$ 3A: 0,17 s	550 mW to $k \times$ 3A: 0,079 s	1
100 mW to 3A: 0,40 s	250 mW to 3A: 0,16 s	550 mW to 3A: 0,073 s	1
50 mW to 1: 0,16 s	100 mW to 1: 0,080 s	250 mW to 1: 0,032 s	1

Equation codes:

1: Total power equation prevails for ω_0 = 6, 8, 10 or 11 µm fibre; hence the maximum power is limited by the AEL expressed as power or energy.

2: Must choose the correct equation based on fibre design (in this case, since ω_0 = 11 microns, the maximum power is limited to the AEL expressed as a power density or energy density.)

Table D.3 – Controlled access example scenarios

Scenario	Wavelength	Maximum power	Hazard level	Requirements
1) Bundled singlemode fibre cable, through public area, but buried underground	1 300 nm	Up to 24 mW per fibre	3A	Labelling
2) Same as 1) but with automatic power reduction to class 1 levels	1 300 nm	Up to 24 mW per fibre	1	No requirements
3) Eight-fibre singlemode ribbon cable, through public area, buried underground	1 300 nm	Up to 1,1 mW per fibre	1	No requirements
4) Same as 3)	1 300 nm	Up to 3 mW per fibre	3A	Labelling
5) Same as 3)	1 300 nm	Up to 24 mW per fibre	3B	Labelling and $k \times$ 3A from connector, otherwise connector requires tool
6) Bundled singlemode fibre cable, through public area, but buried underground	1 300 nm and 1 550 nm	Up to 24 mW per fibre for 1 300 nm and up to 50 mW per fibre for 1 550 nm	3A	Labelling

Table D.4 – Restricted access example scenarios

Scenario	Wavelength	Maximum power	Hazard level	Requirements
1) Bundled singlemode fibre cable, connectorized, in patch panel on industrial premises	1 300 nm	Up to 24 mW per fibre	3A	Labelling
2) Same as 1) but with automatic power reduction to class 1 levels	1 300 nm	Up to 24 mW per fibre	1	No requirements
3) Eight-fibre singlemode ribbon cable, connectorized, in patch panel on industrial premises	1 300 nm	Up to 1,1 mW per fibre	1	No requirements
4) Same as 3)	1 300 nm	Up to 3 mW per fibre	3A	Labelling
5) Same as 3)	1 300 nm	Up to 24 mW per fibre	3B	Not permitted
6) Bundled singlemode fibre cable, connectorized, in patch panel on industrial premises	1 300 nm and 1 550 nm	Up to 24 mW per fibre for 1 300 nm and up to 50 mW per fibre for 1 550 nm	3A	Labelling