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colour inside

Safety of laser products –
Part 13: Measurements for classification of laser products

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Safety of laser products –
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COMMISSION

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SAFETY OF LASER PRODUCTS –

Part 13: Measurements for classification of laser products

FOREWORD

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IEC 60825-13, which is a technical report, has been prepared by IEC technical committee 76: Optical radiation safety and laser equipment.

This second edition cancels and replaces the first edition of IEC 60825-13, published in 2006. It constitutes a technical revision.

The main changes with respect to the previous edition are as follows:

Minor changes and additions have been made in the definitions, classification flow has been updated, apparent source sections have been clarified, scanning has been updated, and more examples and useful conversions have been added to the annexes.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
76/424/DTR	76/447/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.

This technical report is to be used in conjunction with IEC 60825-1:2007.

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 web site 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- withdrawn,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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

SAFETY OF LASER PRODUCTS –

Part 13: Measurements for classification of laser products

1 Scope

This part of IEC 60825 provides manufacturers, test houses, safety personnel, and others with practical guidance on methods to perform radiometric measurements or analyses to establish the emission level of laser energy in accordance with IEC 60825-1:2007 (herein referred to as "the standard"). The measurement procedures described in this technical report are intended as guidance for classification of laser products in accordance with that standard. Other procedures are acceptable if they are better or more appropriate.

Information is provided for calculating accessible emission limits (AELs) and maximum permissible exposures (MPEs), since some parameters used in calculating the limits are dependent upon other measured quantities.

This document is intended to apply to lasers, including extended sources and laser arrays. Users of this document should be aware that the procedures described herein for extended source viewing conditions may yield more conservative results than when using more rigorous methods.

NOTE Work continues on more complex source evaluations and will be provided as international agreement on the methods is reached.

2 Normative references

The following referenced document is indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60825-1:2007, *Safety of laser products – Part 1: Equipment classification and requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions contained in IEC 60825-1:2007 as well as the following terms and definitions apply.

3.1
angular velocity
speed of a scanning beam in radians per second

3.2
beam profile
irradiance distribution of a beam cross-section

3.3
beam waist
minimum diameter of an axis-symmetric beam

Note 1 to entry: For non-symmetric beams, there may be a beam waist along each major axis, each located at a different distance from the source.

3.4
charge-coupled device
CCD
self-scanning semiconductor imaging device that utilizes metal-oxide semiconductor (MOS) technology, surface storage, and information transfer

3.5
critical frequency
pulse repetition frequency above which a pulsed laser can be modelled as CW for the purposes of laser hazard evaluation

3.6
Gaussian beam profile
profile of a laser beam which is operated in the lowest transverse mode, TEM_{00}

NOTE 1 to entry: A Gaussian beam profile may also be produced by passing non-TEM_{00} laser beams through beam shaping optical elements.

3.7
measurement aperture
aperture used for classification of a laser to determine the power or energy that is compared to the AEL for each class

3.8
pulse repetition frequency
PRF
number of pulses occurring per second, expressed in hertz (Hz)

3.9
Q-switch
device for producing very short, high peak power laser pulses by enhancing the storage and dumping of energy in and out of the lasing medium, respectively

3.10
Q-switched laser
aser that emits short, high-power pulses by means of a Q-switch

3.11
Rayleigh length
Z_r
distance from the beam waist in the direction of propagation for which the beam diameter or beam widths are equal to $\sqrt{2}$ times that at the beam waist

NOTE 1 to entry: Rayleigh length is often referred to as ½ the confocal parameter.

3.12
responsivity
R
ratio of the output of a detector to the corresponding input expressed as $R = O/I$, where O is the detector's electrical output and I is the optical power or energy input

3.13
Ultrashort pulse laser
laser that emits pulses shorter than 100 fs and can contain a relatively large spectral content

4 Applicability

4.1 General

This report is intended to be used as a reference guide by (but not limited to) manufacturers, testing laboratories, safety officers, and officials of industrial or governmental authorities. This report also contains interpretations of the standard pertaining to measurement matters and provides supplemental explanatory material.

4.2 Initial considerations

Before attempting to make radiometric measurements for the purpose of product classification or compliance with the other applicable requirements of the standard, there are several parameters of the laser that must first be determined.

a) Emission wavelength(s)

Lasers may emit radiation at one or more distinct wavelengths.

The emission wavelength, wavelengths, or spectral wavelength distribution can typically be obtained from the manufacturer of the laser. Depending on the type of laser, the manufacturer may specify a wavelength range rather than a single value. Otherwise, the emission wavelength, wavelengths or spectral distribution can be determined by measurement, which is beyond the scope of this technical report. See 7.1 for assessing the accessible emission limit (AEL) for multiple wavelengths.

b) Time mode of operation

The time mode of operation refers to the rate at which the energy is emitted. Some lasers emit continuous wave (CW) radiation; other lasers emit energy as pulses of radiation. Pulsed lasers may be single pulsed, Q-switched, repetitively pulsed, or mode locked. Scanned or modulated CW radiation at a fixed location also results in a train of pulses.

In addition, the pulse train may be encoded, but have an average duty factor (emission time as a fraction of elapsed time, expressed as a decimal fraction or percentage).

c) Reasonably foreseeable single fault conditions

The standard specifies that tests shall be performed under each and every reasonably foreseeable single fault condition. It is the responsibility of the manufacturer to ensure that the accessible radiation does not exceed the AEL of the assigned class under all such conditions.

d) Measurement uncertainties

It is important to consider potential sources of error in measurement of laser radiation. Clause 5 of this technical report addresses measurement uncertainties.

e) Collateral radiation (see the standard for definition of collateral radiation)

Collateral radiation entering the measurement aperture may affect measured values of power or energy and pulse duration. Test personnel should ensure that the measurement setup blocks or accounts for collateral radiation that would otherwise reach the detector.

f) Product configuration

If measurements are being made for the purpose of classification, then all controls and settings listed in the operation, maintenance and service instructions must be adjusted in combination to result in the maximum accessible level of radiation. Measurements are also required with the use of accessories that may increase the radiation hazard (for example, collimating optics) which are supplied or offered by the manufacturer of the laser product for use with the product.

NOTE This includes any configuration of the product, which it is possible to attain without using tools or defeating an interlock including configurations and settings against which the operation and maintenance instructions contain warnings. For example, when optical elements such as filters, diffusers or lenses in the optical path of the laser beam can be removed without tools, the product is to be tested in the configuration which results in the highest hazard level. The instruction by the manufacturer not to remove the optical elements cannot justify classification as a lower class. Classification is based on the engineering design of the product and cannot be based on appropriate behaviour of the user.

If measurements are being made to determine the requirements for safety interlocks, labels and information for the user, then the product must be evaluated under the configurations applicable for each of the defined categories of use (operation, maintenance, and service) in accordance with the standard.

IEC technical committee 76 (TC 76) recognises the existence of equivalent measurement procedures, which could yield results that are as valid as the procedures described in this technical report. This report describes measurement procedures that are adequate to meet the measurement requirements of the standard when measurements are needed. In many cases actual radiometric measurements may not be necessary, and compliance with the requirements of the standard can be determined from an analysis of a well-characterised source and the design of the actual product.

Measurements of accessible emission levels must be made at points in space to which human access is possible during operation and maintenance, as applicable. (For example, if operation may require removal of portions of the protective housing and defeat of safety interlocks, measurements must be made at points accessible in that product configuration.) Therefore, under some circumstances it may be necessary to partially disassemble a product to undertake measurements at the required measurement location, particularly when considering reasonably foreseeable single fault conditions. Where a final laser product contains other laser products or systems, it is the final product that is subject to the provisions of the standard.

Measurements must be made with the measuring instrument detector so positioned and so oriented with respect to the laser product as to result in the maximum detection of radiation by the instrument. That is, the detector may have to be moved or the angle changed to obtain a maximum reading on the meter. Appropriate provision must be made to avoid or to eliminate the contribution of collateral radiation to the measurement. For example, it may be necessary to take measurements some distance away from a laser system's output to avoid corrupting the data with radiation from flash lamps or pump diodes/diode lasers. As another example, it may be necessary to filter collateral radiation out with a line filter.

5 Instrumentation requirements

Measurement instruments to be used should comply with the latest edition of IEC 61040. Which instrument class (between class 1 and class 20 giving the approximate value of the possible measurement uncertainty) is to be used depends on the measurement accuracy needed.

Where instruments not fully compliant with IEC 61040 are used, the individual contributions of different parameters to the total measurement uncertainty have to be evaluated separately. The main points to be considered are those given in IEC 61040:

- change of responsivity with time;
- non-uniformity of responsivity over the detector surface;
- change of responsivity during irradiation;
- temperature dependence of responsivity;
- dependence of responsivity on the angle of incidence;
- non-linearity;
- wavelength dependence of responsivity;
- polarisation dependence of responsivity;
- errors in averaging of repetitively pulsed radiation over time;
- zero drift;
- calibration uncertainty.

Calibrations should be traceable to national standards.

Tests for the determination of measurement uncertainties of the instrument should be done according to IEC 61040.

For measurement uncertainties of CCD arrays and cameras see ISO 11146-3.

6 Classification flow

Known or measured parameters of the product enable calculation of AELs and measurement conditions. In addition, fault conditions that increase the hazard must be analysed. Then, a product emission measurement (or several different measurements) will determine if the emission is within the AEL of the class under consideration.

Tables 4 to 9 in the standard provide the accessible emission limits. These tables have rows for the wavelength ranges and columns for the emission durations. Within each row and column entry, there exist one or more formulas containing parameters that are defined in Table 10 in the standard.

The classification flow is illustrated in Figures 1 and 2. The initial approach is to use the default simplified evaluation from 9.3.2 in the standard. It considers the beam to be emitted from a small (point) source with C_6 = 1, a conservative approach if the apparent source size is not known. If the product output appears to be generated by an extended source and is in the 400 nm – 1400 nm range, and if the class determined by the simplified evaluation is not acceptable, then one can alternately determine the class using the more complex evaluation. This involves using additional parameters, including the angular subtense α as a function of distance and the measurement acceptance angle γ_p for the visible photochemical hazard.

First determine whether the laser is pulsed or continuous wave. If the pulse duration is greater than 0,25 s, the laser is considered continuous wave. For a continuous wave laser, refer to the flowchart in Figure 1, and for a pulsed laser, refer to the flowchart in Figure 2.

Next, the wavelength must be determined.

If the laser is pulsed or scanned, the pulse width (PW) and pulse repetition frequency (PRF) must also be determined.

Determine the applicable class or classes. For instance, for a low power application not in the 400 nm – 700 nm region, Class 1, Class 1M and Class 3R might be considered. For a visible wavelength source, Class 1, Class 1M, Class 2, Class 2M and Class 3R might be considered.

Next, the classification time base must be established. This can be determined in terms of default values (8.3e) in the standard), or determined from the definition of the T_2 parameter (Table 10 in the standard), or from considering the particular temporal output properties of the product in question.

This information is needed to locate the row and column entries of Tables 4 to 9 in the standard containing the formula or formulas of interest, and thus to determine the AELs.

Next, the measurement conditions must be determined (9.3 and Table 11 of the standard). For a pulsed laser, several conditions given in 8.3f) of the standard must be evaluated to ensure all fall within the AEL.

Once the AEL has been determined, the output data should be evaluated. The output data may be provided by the manufacturer or measured directly. If output data are provided by the manufacturer, it must be confirmed that the measurements were performed in accordance with Clause 9 of the standard. If the accessible emission is less than the AEL, the laser may be assigned to that class. For a pulsed laser, the AEL of the class applies for all emission durations within the time base.

If the accessible emission is not less than the AEL, a higher class AEL should be chosen and assessed. This is repeated until the AEL is not exceeded or the laser product is assigned to Class 4.

The system must be evaluated in accordance with the standard to insure that a reasonably forseeable single fault cannot cause the laser to emit radiation higher than the AEL for the assigned class. If this criterion is met, the laser classification is known.

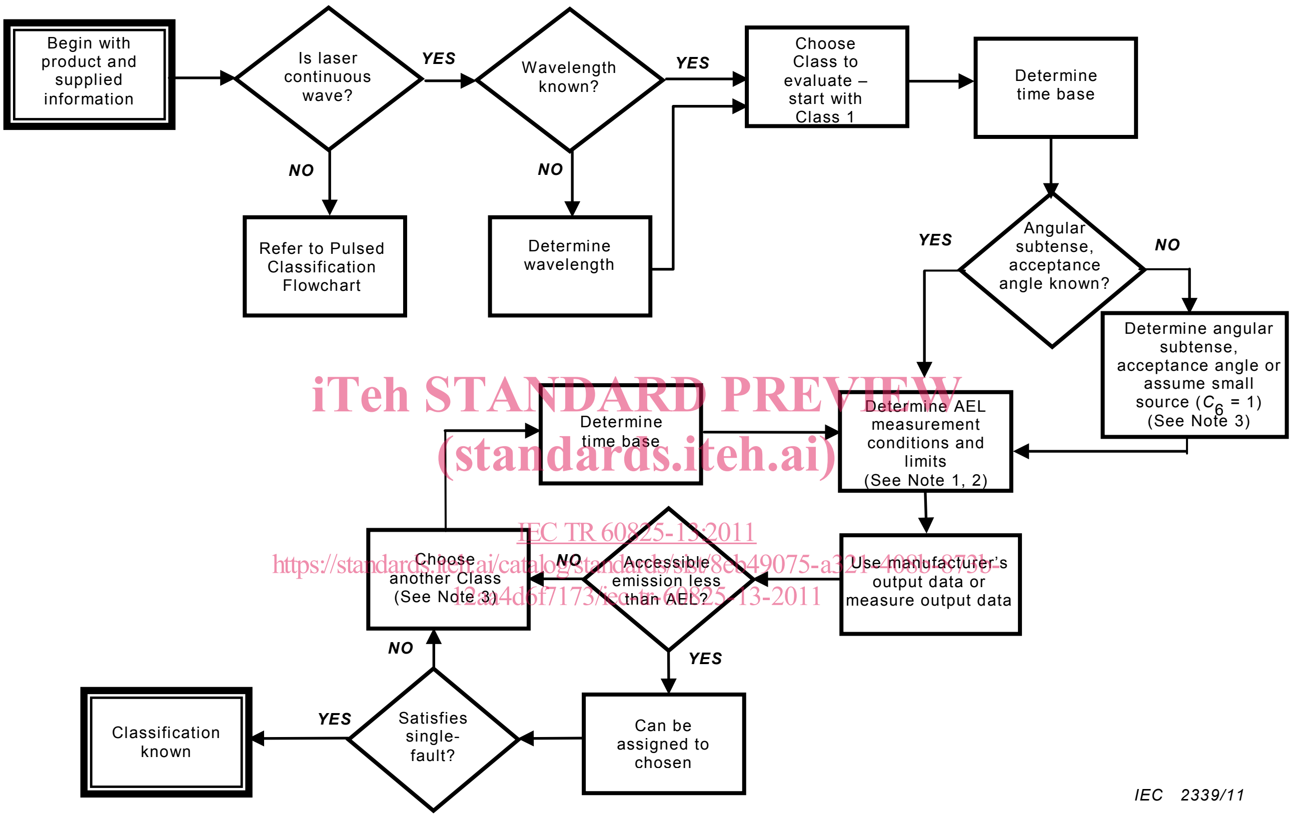

Figure 1 – Continuous wave laser classification flow

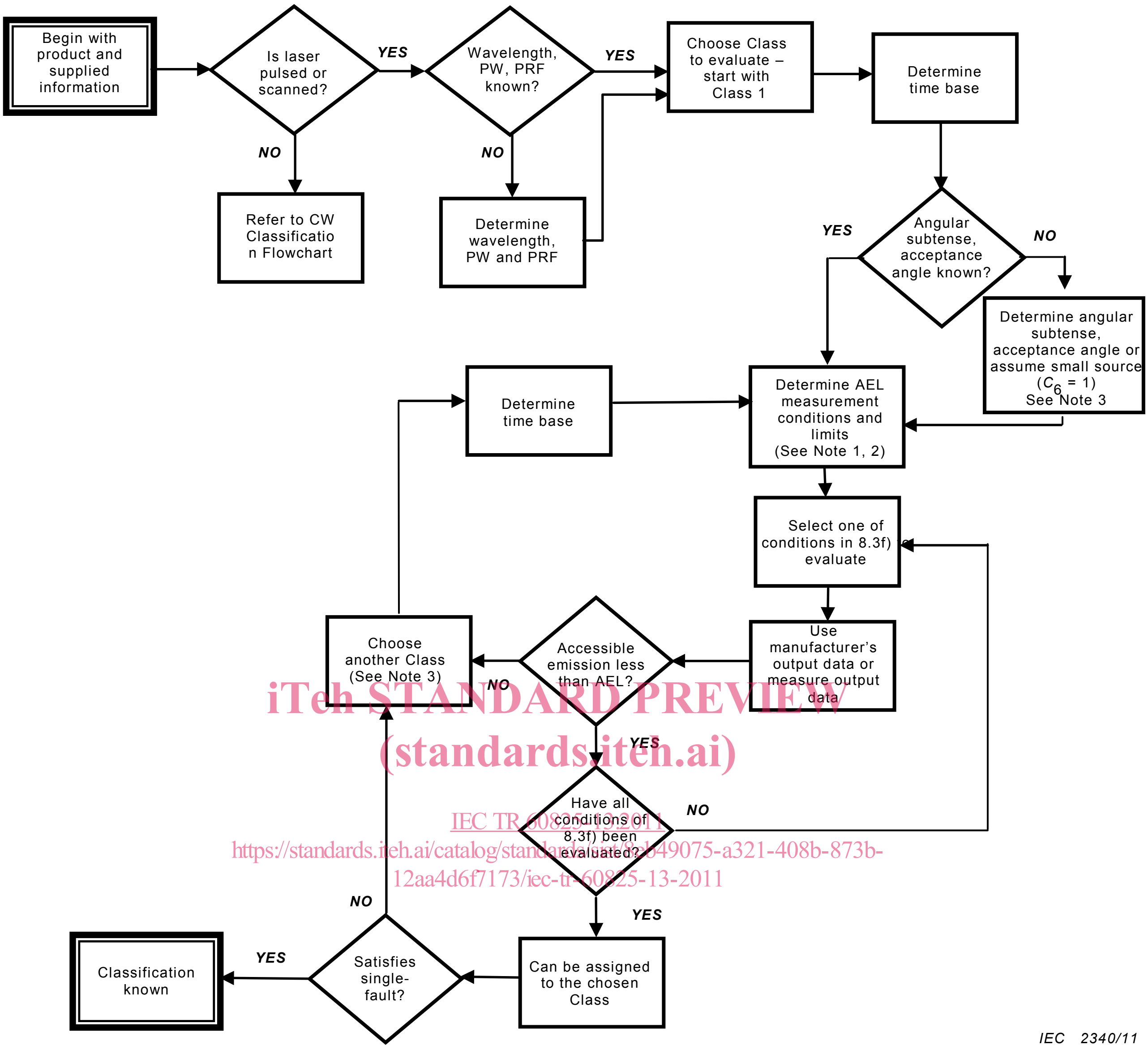

Figure 2 – Pulsed laser classification flow

NOTE 1 There may be more than one condition to be met if a product is to be assigned a certain class. For instance, in the wavelength region 400 nm – 600 nm, neither the thermal nor photochemical limit (each with its own measurement conditions) should be exceeded for a class to apply. Also, if a product has a pulsed output, none of the three limits (single pulse, pulse train and average power) may be exceeded.

NOTE 2 If using an extended source, the AEL will be a function of distance from the source. The most hazardous distance must be used for classification.

NOTE 3 If Class 1 or Class 2 requirements are not satisfied, it is appropriate to evaluate product emission using the Class 1M or Class 2M requirements. If a product emission satisfies the Class 1M or Class 2M requirements, it is not necessary to satisfy the Class 3R requirements.

7 Parameters for calculation of accessible emission limits

7.1 Wavelength (λ)

7.1.1 Wavelength determination

It is usually not necessary to determine this parameter to great accuracy. In general, biological hazards are not strong functions of wavelength. There are several exceptions (refer to Figure 3):

a) 302,5 nm – 315 nm region: over this range, the T_1 and C_2 parameters change significantly;

b) 450 nm – 600 nm region: over this range, the photochemical hazard decreases by a factor of 1 000;

c) 1 150 nm – 1 200 nm region: over this range, the thermal hazard decreases by a factor of eight;

d) 400 nm: at wavelengths greater than 400 nm, the hazard is mainly retinal; at shorter wavelengths, it is mainly non-retinal;

e) 1 400 nm; at wavelengths greater than 1 400 nm, the hazard is mainly non-retinal; at shorter wavelengths, it is mainly retinal.

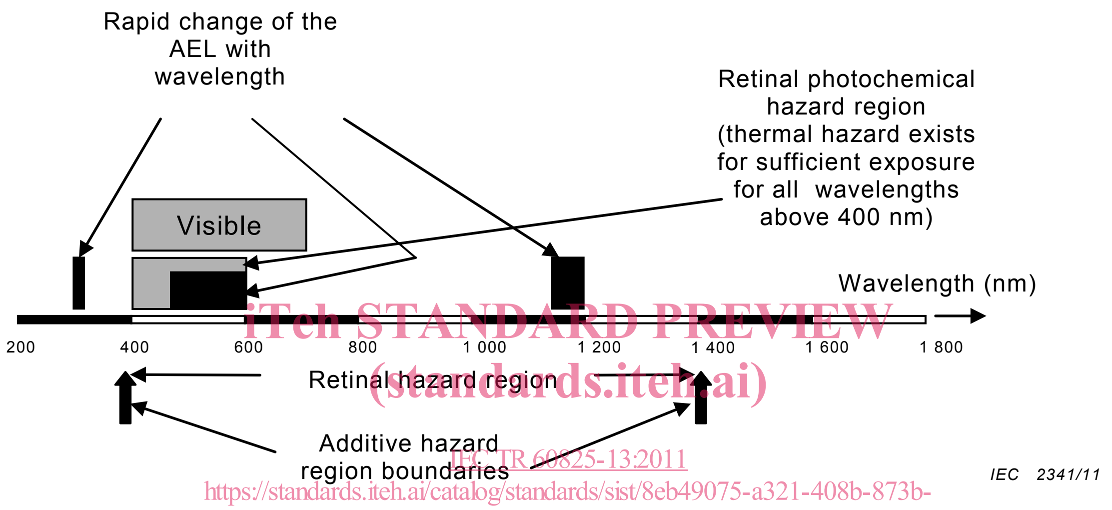

Figure 3 – Important wavelengths and wavelength ranges

For a narrow laser line, a wavelength provided by the manufacturer will likely be all that is necessary, and the remainder of 7.1 as well as 7.2 and 7.3 below need not be considered.

If the range of possible wavelengths (product-to-product variation) is a sizeable fraction of a), b) or c) above, either the most hazardous (shortest) wavelength may be used, or the wavelength may be measured for a given product.

In regions a), b) or c), a piece-wise summation may be required, determining the limit at several wavelengths and weighting by the output associated with that wavelength. This is discussed in detail below in subclauses 7.2.2 and 7.3.

Additive refers to hazards that must be considered together. For instance, multiple emissions less than 400 nm, or between 400 nm and 1 400 nm, or greater than 1 400 nm are additive. For spectrally broad or multiple emissions in each region, the hazards are additive, and a piecewise summation must be performed, as described in item b) of 8.3 of the standard. If a product emits wavelengths in two of these ranges (e.g., 700 nm and 1 500 nm), then the two wavelengths should be considered separately using the relevant AELs for each wavelength. For classification purposes, the higher class will apply.

For lasers whose possible range of output wavelength or output spectrum includes wavelengths greater than 1 400 nm and/or less than 400 nm, special considerations should be made with regard to the AEL. The hazards on either side of the boundary wavelengths are different, and the effects are different. To be assigned a given class, the power or energy in each spectral region must be less than each corresponding AEL.