

# JIS

**JAPANESE INDUSTRIAL STANDARD**

**Radiation safety standards  
for laser products**

**JIS C 6802—1991**

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In the event of any doubt arising,  
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## JAPANESE INDUSTRIAL STANDARD

J I S

## Radiation safety standards for laser products

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1. Scope

This Japanese Industrial Standard specifies the safety bases for the laser light (laser radiation) radiated from laser products and laser systems (hereafter referred to as "laser products") with wavelength range 180 nm to 1 mm. However, this Standard is not applicable for the medical laser product.

Remarks 1. The maximum permissible exposure (MPE) values of this Standard were developed for laser radiation and are not applicable to collateral radiation.

2. In this Standard, the wavelength range  $\lambda_1$  to  $\lambda_2$  means  $\lambda_1 \leq \lambda < \lambda_2$  (e.g. 180 nm to 1 mm means  $180 \text{ nm} \leq \lambda < 1 \text{ mm}$ ).

3. The Standard cited in this Standard is as follows:

JIS C 6801-Glossary of Terms Used in Laser Safety

4. The international standard corresponding to this Standard is as follows:

IEC 825: 1984 Radiation safety of laser products, equipment classification, requirements, and user's guide

Amendment No. 1: 1990

2. Definitions

For the purpose of this Standard, in addition to the definitions in JIS C 6801, the following principal definitions shall apply:

- (1) safe measures for laser radiation To prevent hazard to human body due to laser radiation.
- (2) manufacturer One who carries out the design, manufacture, repair and modification for laser products and the associated safety preventive apparatus, and safe measures.
- (3) user (operator) One who utilizes the laser product by working (operating) or supervising oneself.

Remarks: One who maintains and inspects laser products and the associated safety preventive apparatus, and safe measures is included.

- (4) laser safety officer One who has sufficient knowledge for performing evaluation and safety control of laser hazards.

Remarks: One who has responsibility for the safety control of laser products, let the user (operator) to install the laser product, and to use, to maintain or inspect the installed products is included.

- (5) safety preventive apparatus An apparatus which reserves functions for safety prevention.
- (6) safety preventive measure Measures and means for safety prevention.
- (7) safety preventive device A device in the category of safety preventive apparatus consisting of a fence (e.g. protective enclosure or protective housing) which has the function for preventing human access to exposure of laser radiation or access to laser hazard area.
- (8) maximum permissible exposure The maximum level of laser radiation to which, under normal circumstances, human body (the eye or skin) can be exposed without consequential injury which appears immediately or after a long period of time (hereafter referred to as MPE).
- (9) apparent source The real or virtual object that forms the smallest possible retinal image.

This definition is used to determine the location of the apparent origin of laser radiation in the wavelength range 400 to 1400 nm. Where the apparent source is assumed being located in the eye's range of accommodation ( $\geq 100$  mm). In the limit of vanishing divergence, i.e. in the case of an ideally collimated beam, the location of the apparent source goes to infinity.

### 3. General rule for safe measures of laser product

3.1 General General requirements which must be fulfilled by both manufacturer and user are as follows:

- (1) The manufacturer, laser safety officer and operator shall take an appropriate safe measure to prevent the hazard due to the laser product and its use.
- (2) The laser safety officer shall carry out the education and training concerned with laser safety measure for the operators.
- (3) For the modification as affects any aspect of the product's performance or intended function, the person performing any such modification shall be enforced the reclassification and relabelling of the modified product.

### 3.2 Criteria for exposure of the eye and the skin

3.2.1 General The determination of the threshold values for human body (that is to say, biological damage to the eye or the skin) is essential as to establishment of the safety criteria of laser product. The threshold value at the occurrence of injury varies according to the wavelength of the radiation, the shape of oscillation of laser product or whether the laser source is a point source or an extended source (see Informative reference 1).

- (1) MPE The maximum permissible exposure (MPE) is based one tenth of the laser light internally at which occurrence rate of injury by the laser radiation is a level of 50 %.
- MPE for the eye differs from that for the skin, and the MPE for the eye in intrabeam viewing differs from that in extended source viewing. When the visual angle of viewing light source is greater than the limiting angular subtense  $\alpha_{\min}$ , it is called extended source viewing. MPE's for the eye in intrabeam viewing and extended source viewing are shown in Tables 1 and 2, and the MPE for the skin is shown in Table 3.

Remarks 1. The MPE values should be used as guides in the control of exposure to human body, and should not be regarded as precisely defined boundary between safe and dangerous levels.

In any case, safe preventive measures should be taken to minimize the exposure of the human body to laser radiation within an extent for intended purpose.

2. MPE for the eye means that on the cornea.

Informative reference: The MPE values are related to the wavelength of radiation, the pulse duration or exposure time, the tissue at risk; and for visible and near infrared radiation in the wavelength range 400 nm to 1400 nm, the size of the retinal image.

- (2) Additivity of MPE When a laser emits radiation at several widely different wavelengths, or where pulses are superimposed upon a continuous wave (hereafter denoted as CW) background, calculations of MPE shall be made with the following conditions sufficiently taken into account.

Exposures by radiation from several wavelengths should be assumed to have an additive effect on a proportional basis of spectral effectiveness according to the MPEs of Tables 1 to 3 provided that:

- (a) The difference between pulse widths or exposure times shall be within one order in magnitude.
- (b) The spectral regions which have additional effect are as shown in Table 6.

In Table 6, where the wavelengths radiated are not shown as additive, the MPE should be assessed separately.

For wavelengths which are shown as additive, but when the pulse widths or exposure times are not within one order of magnitude, extreme caution is required (e.g. in the case of simultaneous exposure to pulsed and CW radiation).

Table 1. MPE for the eye at intrabeam viewing  
(see Attached Figs. 1 and 2)

| Wave-length<br>(nm) | Exposure time $t$ (s)                                        |                                                                                                       |                                                      |                                                      |                                                               |                                                    |                                                                                                                                  |                                                |                                                    | Limiting aperture mm |   |
|---------------------|--------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|---------------------------------------------------------------|----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|----------------------------------------------------|----------------------|---|
|                     | $<10^{-9}$                                                   | $10^{-9}$ to $10^{-7}$                                                                                | $10^{-7}$ to $10^{-6}$                               | $10^{-6}$ to $1.8 \times 10^{-5}$                    | $1.8 \times 10^{-5}$ to $5 \times 10^{-5}$                    | $5 \times 10^{-5}$ to $10^{-4}$                    | $10^{-4}$ to $10^{-3}$                                                                                                           | $10^{-3}$ to $10^{-2}$                         | $10^{-2}$ to $3 \times 10^{-1}$                    |                      |   |
| 180 to 302.5        | $3 \times 10^{10}$<br>$\text{W} \cdot \text{m}^{-2}$         | $30 \text{ J} \cdot \text{m}^{-2}$                                                                    |                                                      |                                                      |                                                               |                                                    |                                                                                                                                  |                                                |                                                    |                      | 1 |
| 302.5 to 315        |                                                              | $C_1 \text{ J} \cdot \text{m}^{-2} \{t < T_1\}$<br>$C_2 \text{ J} \cdot \text{m}^{-2} \{t \geq T_1\}$ |                                                      |                                                      |                                                               |                                                    |                                                                                                                                  | $C_2 \text{ J} \cdot \text{m}^{-2}$            |                                                    |                      |   |
| 315 to 400          |                                                              | $C_1 \text{ J} \cdot \text{m}^{-2}$                                                                   |                                                      |                                                      |                                                               |                                                    |                                                                                                                                  | $10^4 \text{ J} \cdot \text{m}^{-2}$           | $10 \text{ W} \cdot \text{m}^{-2}$                 |                      |   |
| 400 to 550          | $5 \times 10^6$<br>$\text{W} \cdot \text{m}^{-2}$            | $5 \times 10^{-3} \text{ J} \cdot \text{m}^{-2}$                                                      |                                                      |                                                      | $18 \times t^{0.75} \text{ J} \cdot \text{m}^{-2}$            |                                                    | $100 \text{ J} \cdot \text{m}^{-2}$                                                                                              |                                                | $10^{-2} \text{ W} \cdot \text{m}^{-2}$            | 7                    |   |
| 550 to 700          |                                                              |                                                                                                       |                                                      |                                                      |                                                               |                                                    | $18 \times t^{0.75} \text{ J} \cdot \text{m}^{-2} \{t < T_2\}$<br>$C_3 \times 10^2 \text{ J} \cdot \text{m}^{-2} \{t \geq T_2\}$ |                                                | $C_3 \times 10^{-2} \text{ W} \cdot \text{m}^{-2}$ |                      |   |
| 700 to 1050         | $5 \times C_4 \times 10^6$<br>$\text{W} \cdot \text{m}^{-2}$ | $5 \times C_4 \times 10^{-3} \text{ J} \cdot \text{m}^{-2}$                                           |                                                      |                                                      | $18 \times C_4 \times t^{0.75} \text{ J} \cdot \text{m}^{-2}$ |                                                    |                                                                                                                                  | $3.2 \times C_4 \text{ W} \cdot \text{m}^{-2}$ |                                                    |                      |   |
| 1050 to 1400        | $5 \times 10^7$<br>$\text{W} \cdot \text{m}^{-2}$            | $5 \times 10^{-2} \text{ J} \cdot \text{m}^{-2}$                                                      |                                                      |                                                      |                                                               | $90 \times t^{0.75} \text{ J} \cdot \text{m}^{-2}$ |                                                                                                                                  | $16 \text{ W} \cdot \text{m}^{-2}$             |                                                    |                      |   |
| 1400 to 1530        | $10^{11} \text{ W} \cdot \text{m}^{-2}$                      | $100 \text{ J} \cdot \text{m}^{-2}$                                                                   | $5600 \times t^{0.25} \text{ J} \cdot \text{m}^{-2}$ |                                                      |                                                               |                                                    | $1000 \text{ W} \cdot \text{m}^{-2}$                                                                                             |                                                |                                                    | 1                    |   |
| 1530 to 1550        |                                                              | $1.0 \times 10^4 \text{ J} \cdot \text{m}^{-2}$                                                       |                                                      | $5600 \times t^{0.25} \text{ J} \cdot \text{m}^{-2}$ |                                                               |                                                    |                                                                                                                                  |                                                |                                                    |                      |   |
| 1550 to $10^5$      |                                                              | $100 \text{ J} \cdot \text{m}^{-2}$                                                                   | $5600 \times t^{0.25} \text{ J} \cdot \text{m}^{-2}$ |                                                      |                                                               |                                                    |                                                                                                                                  |                                                |                                                    |                      |   |
| $10^5$ to $10^6$    |                                                              |                                                                                                       |                                                      |                                                      |                                                               |                                                    |                                                                                                                                  |                                                |                                                    |                      |   |
|                     |                                                              |                                                                                                       |                                                      |                                                      |                                                               |                                                    |                                                                                                                                  |                                                |                                                    | 11                   |   |

Remarks: For repetitively pulse laser radiation, apply the provision of 3.2.2.

Table 2. MPE for the eye at extended source viewing  
(see Attached Figs. 1 and 3)

| Wave- λ<br>length<br>(nm)          | Exposure time t (s)                                                      |                                                                                                              |                                          |                       |                                             |                                                                                                                                                                                                     |                                                                         | Limit-<br>ing<br>aper-<br>ture mm                         |   |
|------------------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|------------------------------------------|-----------------------|---------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|-----------------------------------------------------------|---|
|                                    | <10 <sup>-9</sup>                                                        | 10 <sup>-9</sup> to10 <sup>-7</sup>                                                                          | 10 <sup>-7</sup> to10 <sup>-6</sup>      | 10 <sup>-6</sup> to10 | 10to10 <sup>-3</sup>                        | 10 <sup>3</sup> to10 <sup>4</sup>                                                                                                                                                                   | 10 <sup>4</sup> to3×10 <sup>4</sup>                                     |                                                           |   |
| 180 to 302,5                       | 3×10 <sup>10</sup><br>W·m <sup>-2</sup>                                  | 30 J·m <sup>-2</sup>                                                                                         |                                          |                       |                                             |                                                                                                                                                                                                     |                                                                         |                                                           | 1 |
| 302,5 to 315                       |                                                                          | C <sub>1</sub> J·m <sup>-2</sup> (t<T <sub>1</sub> )<br>C <sub>2</sub> J·m <sup>-2</sup> (t≥T <sub>1</sub> ) |                                          |                       |                                             | C <sub>2</sub> J·m <sup>-2</sup>                                                                                                                                                                    |                                                                         |                                                           |   |
| 315 to 400                         |                                                                          | C <sub>1</sub> J·m <sup>-2</sup>                                                                             |                                          |                       |                                             | 10 <sup>4</sup> J·m <sup>-2</sup>                                                                                                                                                                   | 10 W·m <sup>-2</sup>                                                    |                                                           |   |
| 400 to 550                         | 10 <sup>11</sup> W·m <sup>-2</sup> .<br>sr <sup>-1</sup>                 | 10 <sup>5</sup> ×t <sup>0.33</sup> J·m <sup>-2</sup> .sr <sup>-1</sup>                                       |                                          |                       |                                             | 2.1×10 <sup>6</sup> J·m <sup>-2</sup> .sr <sup>-1</sup>                                                                                                                                             |                                                                         | 21 W·m <sup>-2</sup> .<br>sr <sup>-1</sup>                | 7 |
| 550 to 700                         |                                                                          |                                                                                                              |                                          |                       |                                             | 3.8×10 <sup>4</sup> ×t <sup>0.75</sup> J·m <sup>-2</sup> .sr <sup>-1</sup><br>(t<T <sub>2</sub> )<br>2.1×C <sub>3</sub> ×10 <sup>6</sup> J·m <sup>-2</sup> .sr <sup>-1</sup><br>(t≥T <sub>2</sub> ) |                                                                         | 21×C <sub>3</sub> W·<br>m <sup>-2</sup> .sr <sup>-1</sup> |   |
| 700 to 1050                        | 10 <sup>11</sup> ×C <sub>4</sub> W·<br>m <sup>-2</sup> .sr <sup>-1</sup> | 10 <sup>5</sup> ×C <sub>4</sub> ×t <sup>0.33</sup> J·m <sup>-2</sup> .sr <sup>-1</sup>                       |                                          |                       |                                             | 3.8×10 <sup>4</sup> ×<br>C <sub>4</sub> ×t <sup>0.75</sup> J·<br>m <sup>-2</sup> .sr <sup>-1</sup>                                                                                                  | 6.4×10 <sup>3</sup> ×C <sub>4</sub> W·m <sup>-2</sup> .sr <sup>-1</sup> |                                                           |   |
| 1050 to 1400                       | 5×10 <sup>11</sup> W·<br>m <sup>-2</sup> .sr <sup>-1</sup>               | 5×10 <sup>5</sup> ×t <sup>0.33</sup> J·m <sup>-2</sup> .sr <sup>-1</sup>                                     |                                          |                       |                                             | 1.9×10 <sup>5</sup> ×<br>t <sup>0.75</sup> J·<br>m <sup>-2</sup> .sr <sup>-1</sup>                                                                                                                  | 3.2×10 <sup>4</sup> W·m <sup>-2</sup> .sr <sup>-1</sup>                 |                                                           |   |
| 1400 to 1530                       | 10 <sup>11</sup> W·m <sup>-2</sup>                                       | 100 J·m <sup>-2</sup>                                                                                        | 5600×t <sup>0.25</sup> J·m <sup>-2</sup> |                       |                                             | 1000 W·m <sup>-2</sup>                                                                                                                                                                              |                                                                         |                                                           | 1 |
| 1530 to 1550                       |                                                                          | 1.0×10 <sup>4</sup> J·m <sup>-2</sup>                                                                        |                                          |                       | 5600×t <sup>0.25</sup><br>J·m <sup>-2</sup> |                                                                                                                                                                                                     |                                                                         |                                                           |   |
| 1550 to 10 <sup>5</sup>            |                                                                          | 100 J·m <sup>-2</sup>                                                                                        | 5600×t <sup>0.25</sup> J·m <sup>-2</sup> |                       |                                             |                                                                                                                                                                                                     |                                                                         |                                                           |   |
| 10 <sup>5</sup> to 10 <sup>6</sup> |                                                                          |                                                                                                              |                                          |                       |                                             |                                                                                                                                                                                                     |                                                                         |                                                           |   |

Table 3. MPE for the skin (see Attached Fig. 1)

| Wave- $\lambda$<br>length<br>(nm) | Exposure time $t$ (s)                        |                                                                                                                         |                                                            |                                      |                                    | Limiting<br>aperture<br>mm |
|-----------------------------------|----------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|--------------------------------------|------------------------------------|----------------------------|
|                                   | $<10^{-9}$                                   | $10^{-9}$ to $10^{-7}$                                                                                                  | $10^{-7}$ to10                                             | 10to $10^3$                          | $10^3$ to $3\times10^4$            |                            |
| 180 to 302.5                      | $3\times10^{10} \text{ W}\cdot\text{m}^{-2}$ | $30 \text{ J}\cdot\text{m}^{-2}$                                                                                        |                                                            |                                      |                                    | 1                          |
| 302.5 to 315                      |                                              | $C_1 \text{ J}\cdot\text{m}^{-2} \left( t < T_1 \right)$<br>$C_2 \text{ J}\cdot\text{m}^{-2} \left( t \geq T_1 \right)$ |                                                            |                                      | $C_2 \text{ J}\cdot\text{m}^{-2}$  |                            |
| 315 to 400                        |                                              | $C_1 \text{ J}\cdot\text{m}^{-2}$                                                                                       |                                                            |                                      | $10^4 \text{ J}\cdot\text{m}^{-2}$ |                            |
| 400 to 1400                       | $2\times10^{11} \text{ W}\cdot\text{m}^{-2}$ | $200 \text{ J}\cdot\text{m}^{-2}$                                                                                       | $1.1\times10^4\times t^{0.25} \text{ J}\cdot\text{m}^{-2}$ | $2\,000 \text{ W}\cdot\text{m}^{-2}$ |                                    | 11                         |
| 1400 to $10^5$                    | $10^{11} \text{ W}\cdot\text{m}^{-2}$        | $100 \text{ J}\cdot\text{m}^{-2}$                                                                                       | $5\,600\times t^{0.25} \text{ J}\cdot\text{m}^{-2}$        | $1\,000 \text{ W}\cdot\text{m}^{-2}$ |                                    |                            |
| $10^5$ to $10^6$                  |                                              |                                                                                                                         |                                                            |                                      |                                    |                            |

Remarks to Table 1 to 3.

- Remarks 1. There is only limited evidence about effects for exposures of not more than  $10^{-9}$  s. The MPE's for these exposure times have been derived by assuming that the irradiance, radiance, or radiant exposure continues for  $10^{-9}$  s.
2. Correction factors  $C_1$ ,  $C_2$ ,  $C_3$  and  $C_4$  and break points  $T_1$  and  $T_2$  used for Tables 1 to 3 are defined by the formula given in Table 4 and illustrated in Attached Figs. 4 to 9.

Table 4

| Parameter                                     | Wavelength<br>range nm | Attached<br>Fig. |
|-----------------------------------------------|------------------------|------------------|
| $C_1 = 5.6 \times 10^3 t^{0.25}$              | 302.5 to 400           | 4                |
| $T_1 = 10^{0.8(\lambda-295)} \times 10^{-15}$ | 302.5 to 315           | 5                |
| $C_2 = 10^{0.2(\lambda-295)}$                 | 302.5 to 315           | 6                |
| $T_2 = 10 \times 10^{0.02(\lambda-550)}$      | 550 to 700             | 7                |
| $C_3 = 10^{0.015(\lambda-550)}$               | 550 to 700             | 8                |
| $C_4 = 10^{(\lambda-700)/500}$                | 700 to 1050            | 9                |

3. The limiting angular subtense is the function of the exposure time as shown in the table below and Attached Fig. 11. Attached Fig. 11 is applicable only when the angle subtended at the eye is greater than the limiting angular subtense  $\alpha_{\min}$ .

If  $1050 \leq \lambda < 1400$  nm and  $t < 5 \times 10^{-5}$  s hold, the limiting angular subtense  $\alpha_{\min}$  in Table 5 is increased by a factor of 1.4 (see Attached Fig. 11).

Table 5

| Limiting angular subtense $\alpha_{\min}$ (rad) | Exposure time $t$ (s)                    | Attached Fig. |
|-------------------------------------------------|------------------------------------------|---------------|
| 0.008                                           | $<10^{-9}$                               | 11            |
| $0.00025 \times t^{-0.17}$                      | $10^{-9} \text{ to } 1.8 \times 10^{-5}$ |               |
| $0.015 \times t^{0.21}$                         | $1.8 \times 10^{-5} \text{ to } 10$      |               |
| 0.024                                           | $>10$                                    |               |

Table 6. Additivity of effects on eye (O) and skin (S) of radiation of different spectral regions

| Spectral region   | 180 to 315 nm | 315 to 400 nm | 400 to 1400 nm | 1400 to $10^6$ nm |
|-------------------|---------------|---------------|----------------|-------------------|
| 180 to 315 nm     | O<br>S        |               |                |                   |
| 315 to 400 nm     |               | O<br>S        | S              | O<br>S            |
| 400 to 1400 nm    |               | S             | O<br>S         | S                 |
| 1400 to $10^6$ nm |               | O<br>S        | S              | O<br>S            |

Remarks: The spectral regions are expressed as additive by the symbols (O) for ocular and (S) for skin exposure in the matrix of Table 6.

The regions without symbols mean that the regions are not additive.

**3.2.2 Limiting apertures** An appropriate aperture should be used for all measurements and calculations of exposure values. This is the limiting aperture and is defined in terms of the diameter of a circular area over which the irradiance or radiant exposure is to be averaged. Values for limiting apertures are shown in Tables 1 to 3.

Remarks: These values of ocular exposures to visible and near-infrared radiation are measured over a 7 mm diameter aperture (pupil). The MPE value is not to be adjusted to take into account smaller pupil diameters. Additionally, the MPE values in Table 2 for wavelength 400 nm to 1400 nm should be averaged over an angle less than  $\alpha_{\min}$ .

**3.2.3 Repetitively pulsed or modulated lasers** The following methods shall be used to determine the MPE applicable to the exposure to repetitively pulsed or modulated lasers.

- (1) The MPE at wavelength 400 nm to 1400 nm is determined by using the most restrictive of requirements (a), (b) and (c) as appropriate.

The MPE at other wavelengths is determined by using the most restrictive of requirements (a) and (b).

- (a) The exposure from any single pulse within the train shall not exceed the MPE to a single pulse.
- (b) The average irradiance for a pulse train of duration  $T$  shall not exceed the MPE given in Tables 1 to 3 for a single pulse of duration  $T$ .
- (c) The exposure from any single pulse within the train shall not exceed the  $MPE_{train}$  calculated from the following formula (see Attached Fig. 10):

$$MPE_{train} = MPE_{single} \times N^{-1/4}$$

where,  $MPE_{train}$ : exposure from any single pulse in the train

$MPE_{single}$ : MPE for a single pulse

$N$ : number of pulses expected in an exposure

### 3.3 Evaluation of hazard and classification

**3.3.1 General** Because of the wide ranges possible for the wavelength, energy content and pulse characteristics of a laser beam, the hazards arising in their use vary widely. Since it is impossible to regard lasers as a single group to which common safety limits can apply, it is necessary to classify laser products.

**3.3.2 Classification of laser products** Laser products are grouped into the following general classes for each of which accessible emission limits (AELs) are specified:

- (1) Class 1 lasers Class 1 lasers are those that are inherently safe (so that the maximum permissible exposure level cannot be exceeded under any condition) or are safe by virtue of their engineering design. The upper limits of AEL of Class 1 are given in Table 7 and are derived from the most limiting MPE values.
- (2) Class 2 lasers Class 2 lasers are low power devices emitting visible radiation (in the wavelength range 400 nm to 700 nm) and which may operate in either CW or pulsed mode. The output power or energy of Class 2 laser with a duration of radiation up to 0.25 s shall be limited to the AEL of corresponding Class 1 laser. For a CW laser, the upper limit of the output power of Class 2 laser with a duration of radiation 0.25 s or more, is 1 mW (see Table 8).

**Informative reference:** These lasers are not intrinsically safe but eye protection is normally afforded by aversion responses including the blink reflex.

- (3) Class 3 A lasers Class 3 A lasers are lasers whose AEL in the spectral region of 400 nm to 700 nm is up to 5 mW for CW lasers, or five times the limit of Class 2 for repetitively-pulsed and scanning lasers in output power or energy. However, the irradiance at any point in the visible beam must not exceed  $25 \text{ W} \cdot \text{m}^{-2}$  (see Table 9).

For other spectral regions the laser radiation must not exceed five times the AEL for Class 1 and the output irradiance or radiant exposure listed in Table 9 must also not be exceeded.

Informative reference: For lasers emitting in the range from 400 nm to 700 nm, protection to the unaided eye is afforded by aversion responses including the blink reflex. But, direct intrabeam viewing of Class 3 A laser beams with optical aids (e.g., binocular telescopes) may be hazardous.

- (4) Class 3 B lasers Class 3 B lasers may emit visible and/or invisible radiation at levels not exceeding the AEL's specified in Table 10. CW lasers must not exceed 0.5 W and the radiant exposure from pulsed lasers must be not more than  $10^5 \text{ J}\cdot\text{m}^{-2}$ .

Remark: In this Standard, simple expression of Class 3 laser includes Class 3 A laser and Class 3 B laser.

Informative reference: Direct intrabeam viewing near these devices is always hazardous. Viewing unfocused pulsed laser radiation by diffuse reflection is not hazardous and under certain conditions CW laser beam may safely be viewed via a diffuse reflector.

- (5) Class 4 lasers Class 4 laser are high power devices with output power exceeding the AEL's specified in Table 10 for Class 3 B.

Informative reference: All class 4 lasers are capable of producing hazardous reflections. They may cause skin injuries and could also constitute a fire hazard. Their use requires extreme caution.

### 3.3.3 Classification procedure Classification procedure is as follows:

- (1) Responsibility for classification It is the responsibility of the manufacturer to provide correct classification of a laser product.

If the modification of a previously classified laser product affects any aspect of the product's performance or intended functions, the person or organization who performed such a modification is responsible for ensuring the reclassification and relabelling of the laser product (see 4.3).

- (2) Classification of laser products

- (2.1) General The product shall be classified on the basis of that combination of output power(s) and wavelength(s) of the accessible laser radiation over the full range of operational capability at any time after manufacture which results in its allocation to the highest appropriate class. The accessible emission limit (AELs) for Class 1, Class 2, Class 3 A and Class 3B (listed in order of increasing hazard) are given in Table 7 to 10 respectively.

- (2.2) Time basis for classification In this Standard three time basis (a) (b) and (c) given below are used. If the reduced duration [(b) or (c)] is used, this shall be recorded on the explanatory label with the intended use of the laser.
- (a) 30000 s for laser radiation of wavelengths less than or equal to 400 nm and for laser radiation of wavelengths greater than 400 nm where intentional viewing was inherent in the design or function of the laser product.
  - (b) 1000 s for laser radiation of wavelengths greater than 400 nm unless intentional viewing was inherent in the design or function of the laser product.
  - (c) 100 s for the Class 3 A in the wavelength range of 700 to 1400 nm.
- (2.3) Radiation of a single wavelength Single wavelength laser products shall be classified according to the laser radiation passing through the aperture as given in Table 7 to 10.
- (2.4) Radiation of multiple wavelengths Laser products which emit multiple wavelengths shall be classified as follows:
- (a) A laser product emitting two or more wavelengths in spectral regions, shown as additive in Table 6, is assigned to a class in accordance with Tables 7 to 10 when the sum of the ratios of the laser radiation passing through the aperture to the AELs for those wavelengths is greater than unity for all lower classes but does not exceed unity for the class assigned.
  - (b) A laser product emitting two or more wavelengths not shown as additive in Table 6, is assigned to a class when the laser radiation passing through the aperture exceeds the AELs of all lower classes for any wavelength but does not exceed the AEL for the class assigned for any wavelength.
- (2.5) Human accessibility considerations for classification (protective housing) If through any port in the protective housing a portion of the body can be exposed to laser radiation by failure mode, or insertion of a portion of the body, the laser product shall be classified, labeled, and otherwise treated in conformity with the radiation existing at that site and the portion of the body to which that radiation can be presented.
- (2.6) Class 1 dual limits In the wavelength range from 400 nm to 1400 nm dual limits exist for Class 1 laser products. A laser product is classified as Class 1 if it complies with at least one of the two sets of AEL values ("radiant power or energy" and "radiance or integrated radiance") specified in Table 7.

- (2.7) Angular subtense  $\alpha$  For the purpose of classification the angular subtense  $\alpha$  used as the basis for distinguishing direct intrabeam viewing from extended source viewing shall be calculated (or measured) at the smallest possible distance from the apparent source but not less than 100 mm (see limiting angular subtense  $\alpha_{\min}$  in JIS C 6801).

3.3.4 Repetitively pulsed or modulated lasers Since there are only limited data on multiple pulse exposure criteria, the following methods shall be used to determine the AEL applicable to exposure to repetitively pulsed radiation.

- (1) The AEL for wavelengths 400 nm to 1400 nm is determined by using the most restrictive of requirements (a), (b) and (c) as appropriate. For other wavelengths the AEL is determined by using the most restrictive of requirements (a) and (b).
  - (a) The exposure from any single pulse within the train shall not exceed the AEL for a single pulse.
  - (b) The average power for a pulse train of duration  $T$  shall not exceed the power corresponding to the AEL given in Tables 7 to 10, respectively for a single pulse of duration  $T$ .
  - (c) The exposure from any single pulse within the train shall not exceed the  $AEL_{\text{train}}$  calculated from the following formula (see Attached Fig. 10):

$$AEL_{\text{train}} = AEL_{\text{single}} \times N^{-1/4}$$

where,  $AEL_{\text{train}}$ : exposure from any single pulse in the train

$AEL_{\text{single}}$ : AEL for a single pulse

$N$ : number of pulses during the applicable time base

Table 7. AEL for class 1 laser products (see Attached Figs. 12 and 13)

| Wave- λ<br>length<br>(nm) |                                 | Emission duration $t$ (s)                                |                                                                                         |                                        |                                        |                                                 |                                        |                                                                                                                                                                          |                                   |                                                                  |
|---------------------------|---------------------------------|----------------------------------------------------------|-----------------------------------------------------------------------------------------|----------------------------------------|----------------------------------------|-------------------------------------------------|----------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|------------------------------------------------------------------|
|                           |                                 | $<10^{-9}$                                               | $10^{-9}$ to $10^{-7}$                                                                  | $10^{-7}$ to $10^{-6}$                 | $10^{-6}$ to<br>$1.8 \times 10^{-5}$   | $1.8 \times 10^{-5}$<br>to $5 \times 10^{-5}$   | $5 \times 10^{-5}$<br>to $10$          | $10$ to $10^3$                                                                                                                                                           | $10^3$ to $10^4$                  | $10^4$ to<br>$3 \times 10^4$                                     |
| 180 to 302.5              |                                 | $2.4 \times 10^4$ W                                      | $2.4 \times 10^{-5}$ J                                                                  |                                        |                                        |                                                 |                                        |                                                                                                                                                                          |                                   |                                                                  |
| 302.5 to 315              |                                 |                                                          | $7.9 \times 10^{-7} C_1$ J ( $t < T_1$ )<br>$7.9 \times 10^{-7} C_2$ J ( $t \geq T_1$ ) |                                        |                                        |                                                 |                                        | $7.9 \times 10^{-7}$ $C_2$ J                                                                                                                                             |                                   |                                                                  |
| 315 to 400                |                                 |                                                          | $7.9 \times 10^{-7} \times C_1$ J                                                       |                                        |                                        |                                                 |                                        | $7.9 \times 10^{-3}$ J                                                                                                                                                   | $7.9 \times 10^{-6}$ W            |                                                                  |
| 400 to 550                | Radiant power or energy         | 200 W                                                    | $2 \times 10^{-7}$ J                                                                    |                                        |                                        | $7 \times 10^{-4} \times t^{0.75}$ J            |                                        | $3.9 \times 10^{-3}$ J                                                                                                                                                   |                                   | $3.9 \times 10^{-7}$ W                                           |
|                           | Radiance or integrated radiance | $10^{11}$ W·m <sup>-2</sup> .sr <sup>-1</sup>            | $10^5 \times t^{0.33}$ J·m <sup>-2</sup> .sr <sup>-1</sup>                              |                                        |                                        |                                                 |                                        | $2.1 \times 10^5$ J·m <sup>-2</sup> .sr <sup>-1</sup>                                                                                                                    |                                   | $21$ W·m <sup>-2</sup> .sr <sup>-1</sup>                         |
| 550 to 700                | Radiant power or energy         | 200 W                                                    | $2 \times 10^{-7}$ J                                                                    |                                        |                                        | $7 \times 10^{-4} \times t^{0.75}$ J            |                                        | $7 \times 10^{-4} \times t^{0.75}$ J<br>( $t < T_2$ )<br>$3.9 \times 10^{-3} \times C_3$ J<br>( $t \geq T_2$ )                                                           |                                   | $3.9 \times 10^{-7} \times C_3$ W                                |
|                           | Radiance or integrated radiance | $10^{11}$ W·m <sup>-2</sup> .sr <sup>-1</sup>            | $10^5 \times t^{0.33}$ J·m <sup>-2</sup> .sr <sup>-1</sup>                              |                                        |                                        |                                                 |                                        | $3.9 \times 10^4 \times t^{0.75}$ J·m <sup>-2</sup> .sr <sup>-1</sup> ( $t < T_2$ )<br>$2.1 \times 10^5 \times C_3$ J·m <sup>-2</sup> .sr <sup>-1</sup> ( $t \geq T_2$ ) |                                   | $21 \times C_3$ W·m <sup>-2</sup> .sr <sup>-1</sup>              |
| 700 to 1050               | Radiant power or energy         | $200 \times C_4$ W                                       | $2 \times 10^{-7} \times C_4$ J                                                         |                                        |                                        | $7 \times 10^{-4} \times t^{0.75} \times C_4$ J |                                        |                                                                                                                                                                          | $1.2 \times 10^{-4} \times C_4$ W |                                                                  |
|                           | Radiance or integrated radiance | $10^{11} \times C_4$ W·m <sup>-2</sup> .sr <sup>-1</sup> | $10^5 \times t^{0.33} \times C_4$ J·m <sup>-2</sup> .sr <sup>-1</sup>                   |                                        |                                        |                                                 |                                        | $3.9 \times 10^4 \times t^{0.75} \times C_4$ J·m <sup>-2</sup> .sr <sup>-1</sup>                                                                                         |                                   | $6.4 \times 10^3 \times C_4$ W·m <sup>-2</sup> .sr <sup>-1</sup> |
| 1050 to 1400              | Radiant power or energy         | $2 \times 10^3$ W                                        | $2 \times 10^{-6}$ J                                                                    |                                        |                                        |                                                 | $3.5 \times 10^{-3} \times t^{0.75}$ J |                                                                                                                                                                          | $6 \times 10^{-4}$ W              |                                                                  |
|                           | Radiance or integrated radiance | $5 \times 10^{11}$ W·m <sup>-2</sup> .sr <sup>-1</sup>   | $5 \times 10^5 \times t^{0.33}$ J·m <sup>-2</sup> .sr <sup>-1</sup>                     |                                        |                                        |                                                 |                                        | $1.9 \times 10^5 \times t^{0.75}$ J·m <sup>-2</sup> .sr <sup>-1</sup>                                                                                                    |                                   | $3.2 \times 10^4$ W·m <sup>-2</sup> .sr <sup>-1</sup>            |
| 1400 to 1530              |                                 | $8 \times 10^4$ W                                        | $8 \times 10^{-5}$ J                                                                    | $4.4 \times 10^{-3} \times t^{0.25}$ J |                                        |                                                 |                                        | $8 \times 10^{-4}$ W                                                                                                                                                     |                                   |                                                                  |
| 1530 to 1550              |                                 |                                                          | $8 \times 10^{-3}$ J                                                                    |                                        | $4.4 \times 10^{-3} \times t^{0.25}$ J |                                                 |                                        |                                                                                                                                                                          |                                   |                                                                  |
| 1550 to $10^5$            |                                 |                                                          | $8 \times 10^{-5}$ J                                                                    | $4.4 \times 10^{-3} \times t^{0.25}$ J |                                        |                                                 |                                        |                                                                                                                                                                          |                                   |                                                                  |
| $10^5$ to $10^6$          |                                 | $10^7$ W                                                 | $10^{-2}$ J                                                                             | $0.56 \times t^{0.25}$ J               |                                        |                                                 |                                        | $0.1$ W                                                                                                                                                                  |                                   |                                                                  |

Table 8. AEL for class 2 laser products

| Wavelength<br>$\lambda$ (nm) | Emission<br>duration $t$ (s) | AEL                                                  |
|------------------------------|------------------------------|------------------------------------------------------|
| 400 to 700                   | $t < 0.25$<br>$t \geq 0.25$  | Same as AEL for class 1<br>(see Table 5) $10^{-3}$ W |

Table 9. AEL for class 3 A laser products

| Wave- $\lambda$<br>length<br>(nm) | Emission duration $t$ (s)                                                                 |                                                                                                                                                                                                   |                                                                                                           |                                      |                                                                                                                      |                                                                                                       |                                                                                                                                         |                                                                                 |                                                                        |
|-----------------------------------|-------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|--------------------------------------|----------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|------------------------------------------------------------------------|
|                                   | $<10^{-9}$                                                                                | $10^{-9}$ to $10^{-7}$                                                                                                                                                                            | $10^{-7}$ to $10^{-6}$                                                                                    | $10^{-6}$ to<br>$1.8 \times 10^{-5}$ | $1.8 \times 10^{-5}$<br>to $5 \times 10^{-5}$                                                                        | $5 \times 10^{-5}$<br>to 0.25                                                                         | 0.25 to 10                                                                                                                              | 10 to $10^3$                                                                    | $10^3$ to<br>$3 \times 10^4$                                           |
| 180 to 302.5                      | $3 \times 10^{10}$<br>$\text{W} \cdot \text{m}^{-2}$                                      | $30 \text{ J} \cdot \text{m}^{-2}$                                                                                                                                                                |                                                                                                           |                                      |                                                                                                                      |                                                                                                       |                                                                                                                                         |                                                                                 |                                                                        |
| 302.5 to 315                      | $1.2 \times 10^5$<br>W and $3 \times 10^{10}$<br>$\text{W} \cdot \text{m}^{-2}$           | $4 \times C_2 \times 10^{-6} \text{ J}$ and $C_2 \text{ J} \cdot \text{m}^{-2}$ ( $t \geq T_1$ )<br>$4 \times 10^{-8} \times C_1 \text{ J}$ and $C_1 \text{ J} \cdot \text{m}^{-2}$ ( $t < T_1$ ) |                                                                                                           |                                      |                                                                                                                      |                                                                                                       |                                                                                                                                         | $4 \times C_2 \times 10^{-6} \text{ J}$ and $C_2 \text{ J} \cdot \text{m}^{-2}$ |                                                                        |
| 315 to 400                        |                                                                                           | $4 \times 10^{-6} \times C_1 \text{ J}$ and $C_1 \text{ J} \cdot \text{m}^{-2}$                                                                                                                   |                                                                                                           |                                      |                                                                                                                      |                                                                                                       |                                                                                                                                         | $4 \times 10^{-2} \text{ J}$<br>and $10^4 \text{ J} \cdot \text{m}^{-2}$        | $4 \times 10^{-5} \text{ W}$<br>and $10 \text{ W} \cdot \text{m}^{-2}$ |
| 400 to 700                        | 1 000 W<br>and $5 \times 10^6$<br>$\text{W} \cdot \text{m}^{-2}$                          | $10^{-6} \text{ J}$ and $5 \times 10^{-3} \text{ J} \cdot \text{m}^{-2}$                                                                                                                          |                                                                                                           |                                      | $3.5 \times 10^{-3} \times t^{0.75} \text{ J}$ and<br>$18 \times t^{0.75} \text{ J} \cdot \text{m}^{-2}$             |                                                                                                       | $5 \times 10^{-3} \text{ W}$ and $25 \text{ W} \cdot \text{m}^{-2}$<br>(Aversion responses protect<br>for emission $> 0.25 \text{ s}$ ) |                                                                                 |                                                                        |
| 700 to 1 050                      | $1\,000 \times C_4$<br>W and $5 \times C_4 \times 10^4$<br>$\text{W} \cdot \text{m}^{-2}$ | $10^{-6} \times C_4 \text{ J}$ and $5 \times C_4 \times 10^{-3} \text{ J} \cdot \text{m}^{-2}$                                                                                                    |                                                                                                           |                                      | $3.5 \times 10^{-3} t^{0.75} \times C_4 \text{ J}$ and $18 \times C_4 \times t^{0.75} \text{ J} \cdot \text{m}^{-2}$ |                                                                                                       |                                                                                                                                         | $6 \times 10^{-4} C_4$<br>W and $3.2 \times C_4 \text{ W} \cdot \text{m}^{-2}$  |                                                                        |
| 1 050 to 1 400                    | $10^4 \text{ W}$ and<br>$5 \times 10^7 \text{ W} \cdot \text{m}^{-2}$                     | $10^{-5} \text{ J}$ and $5 \times 10^{-2} \text{ J} \cdot \text{m}^{-2}$                                                                                                                          |                                                                                                           |                                      |                                                                                                                      | $1.8 \times 10^{-2} \times t^{0.75} \text{ J}$ and $90 \times t^{0.75} \text{ J} \cdot \text{m}^{-2}$ |                                                                                                                                         | $3 \times 10^{-3} \text{ W}$<br>and $16 \text{ W} \cdot \text{m}^{-2}$          |                                                                        |
| 1 400 to 1 530                    | $4 \times 10^5 \text{ W}$<br>and $10^{11}$<br>$\text{W} \cdot \text{m}^{-2}$              | $4 \times 10^{-4} \text{ J}$<br>and $100 \text{ J} \cdot \text{m}^{-2}$                                                                                                                           | $2.2 \times 10^{-2} \times t^{0.25} \text{ J}$ and $5\,600 \times t^{0.25} \text{ J} \cdot \text{m}^{-2}$ |                                      |                                                                                                                      |                                                                                                       |                                                                                                                                         | $4 \times 10^{-3} \text{ W}$ and $1\,000 \text{ W} \cdot \text{m}^{-2}$         |                                                                        |
| 1 530 to 1 550                    |                                                                                           | $1.0 \times 10^4 \text{ J} \cdot \text{m}^{-2}$                                                                                                                                                   | $2.2 \times 10^{-2} \times t^{0.25} \text{ J}$ and $5\,600 \times t^{0.25} \text{ J} \cdot \text{m}^{-2}$ |                                      |                                                                                                                      |                                                                                                       |                                                                                                                                         |                                                                                 |                                                                        |
| 1 550 to 4 000                    |                                                                                           | $4 \times 10^{-4} \text{ J}$<br>and $100 \text{ J} \cdot \text{m}^{-2}$                                                                                                                           | $2.2 \times 10^{-2} \times t^{0.25} \text{ J}$ and $5\,600 \times t^{0.25} \text{ J} \cdot \text{m}^{-2}$ |                                      |                                                                                                                      |                                                                                                       |                                                                                                                                         |                                                                                 |                                                                        |
| 4 000 to $10^6$                   | $10^{11} \text{ W} \cdot \text{m}^{-2}$                                                   | $100 \text{ J} \cdot \text{m}^{-2}$                                                                                                                                                               | $5\,600 \times t^{0.25} \text{ J} \cdot \text{m}^{-2}$                                                    |                                      |                                                                                                                      |                                                                                                       |                                                                                                                                         | $1\,000 \text{ W} \cdot \text{m}^{-2}$                                          |                                                                        |

Table 10. AEL for class 3 B laser products

| Wave- $\lambda$<br>length<br>(nm) | Emission duration $t$ (s)                               |                                                                                                             |                                  |
|-----------------------------------|---------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|----------------------------------|
|                                   | $<10^{-9}$                                              | $10^{-9}$ to 0.25                                                                                           | 0.25 to $3 \times 10^4$          |
| 180 to 302.5                      | $3.8 \times 10^5 \text{ W}$                             | $3.8 \times 10^{-4} \text{ J}$                                                                              | $1.5 \times 10^{-3} \text{ W}$   |
| 302.5 to 315                      | $1.25 \times 10^4 \times C_2 \text{ W}$                 | $1.25 \times 10^{-5} \times C_2 \text{ J}$                                                                  | $5 \times 10^{-5} C_2 \text{ W}$ |
| 315 to 400                        | $1.25 \times 10^8 \text{ W}$                            | $0.125 \text{ J}$                                                                                           | $0.5 \text{ W}$                  |
| 400 to 700                        | $3.14 \times 10^{11} \text{ W} \cdot \text{m}^{-2}$     | $3.14 \times 10^5 t^{0.33} \text{ J} \cdot \text{m}^{-2}$<br>and $< 10^5 \text{ J} \cdot \text{m}^{-2}$     |                                  |
| 700 to 1050                       | $3.14 \times 10^{11} C_4 \text{ W} \cdot \text{m}^{-2}$ | $3.14 \times 10^5 C_4 t^{0.33} \text{ J} \cdot \text{m}^{-2}$<br>and $< 10^5 \text{ J} \cdot \text{m}^{-2}$ |                                  |
| 1050 to 1400                      | $1.57 \times 10^{12} \text{ W} \cdot \text{m}^{-2}$     | $1.57 \times 10^6 t^{0.33} \text{ J} \cdot \text{m}^{-2}$<br>and $< 10^5 \text{ J} \cdot \text{m}^{-2}$     |                                  |
| 1400 to $10^6$                    | $10^{14} \text{ W} \cdot \text{m}^{-2}$                 | $10^5 \text{ J} \cdot \text{m}^{-2}$                                                                        |                                  |

Remarks to Tables 7 to 10.

Remarks 1. There is only limited evidence about the effect at exposure of not more than  $10^{-9} \text{ s}$ . The AEL's for such an exposure time are those when the irradiance, radiance, or radiant exposure is maintained for  $10^{-9} \text{ s}$ .

Remarks 2. Correction factors  $C_1$  to  $C_4$  and breakpoints  $T_1$  and  $T_2$  used in Tables 7 to 10 are defined by the equation of Table 11 and are shown in Attached Figs. 4 to 9.

Table 11

| Parameter                                       | Wavelength range nm | Attached figure |
|-------------------------------------------------|---------------------|-----------------|
| $C_1 = 5.6 \times 10^3 \lambda^{0.25}$          | 302.5 to 400        | 4               |
| $T_1 = 10^{0.8(\lambda - 295)} \times 10^{-15}$ | 302.5 to 315        | 5               |
| $C_2 = 10^{0.2(\lambda - 295)}$                 | 302.5 to 315        | 6               |
| $T_2 = 10 \times 10^{0.02(\lambda - 550)}$      | 550 to 700          | 7               |
| $C_3 = 10^{0.015(\lambda - 550)}$               | 550 to 700          | 8               |
| $C_4 = 10^{(\lambda - 700)/500}$                | 700 to 1050         | 9               |

**3.3.5 Semiconductor laser light source** Semiconductor lasers used for optical fiber transmission systems (OFTS) or optical transmitting equipment accommodating the semiconductor laser for OFTS have the nature of largely divergent emitting beam with the various divergence angles which differs from the nature of usual solid state lasers or gas lasers.

As explained above, an exposure dose to the eye greatly depends upon the type of light source and the distance between the light source and the eye, it is necessary to consider these matters for the classification.

Also the oscillation wavelength of semiconductor laser light sources is distributed from visual to near-infrared spectral region. Therefore, it is necessary for the exposure dose evaluation to take the difference in hazard due to wavelength into consideration.

Thus, the accessible emission limit (AEL) applicable for exposure to the semiconductor laser light source for OFTS may be defined in accordance with the following:

- (1) As the emitting diameter of semiconductor laser light sources is at most 150  $\mu\text{m}$ , all cases belong to the viewing criterion within the limiting angular subtense  $\alpha_{\min}$  even if observed from the nearpoint of accommodation (100 mm) (see Attached Fig. 11). Consequently, the maximum permissible exposure (MPE) to the intrabeam viewing can be applied, and the Class 1 AEL values for radiance or integrated radiance defined as one of the Class 1 dual limits are not applicable. However, for light sources of emitting diameter 150  $\mu\text{m}$  to 2.4 mm, whether the source is within the limiting angular subtense  $\alpha_{\min}$  or not is discriminated by taking the exposure time and the wavelength into consideration, and the provision for the integrated radiance shall be applied if the source exceeds the limiting angular subtense  $\alpha_{\min}$ .

- (2) Generally, the exposure dose to eye increases with decreasing divergence angle ( $\theta$ ) of the light source (full angle at half maximum) and distance ( $d$ ) between the light source and the eye. As MPE values and AEL values are specified in the standpoint of the retinal hazard for lasers with wavelength less than 1400 nm, at a distance ( $d$ ) less than the nearpoint of accommodation, the possible hazard is reduced, in spite of increase of total exposure dose, because of the faded and spreaded retinal image. Consequently, the nearpoint of accommodation (100 mm) can be used as the distance ( $d$ ) for the worst case, therefore the classification may be determined by means of exposure dose through the limiting aperture (7 mm diameter) placed at the distance of 100 mm from the light source for the wavelength range less than 1400 nm. Meanwhile, for wavelength not less than 1400 nm, the injury by absorption in the anterior structures of the eye (for instance, cornea) is mainly caused, therefore, an injury is apt to occur when the distance ( $d$ ) between the light source and the eye becomes shorter. Since the case when the distance ( $d$ ) becomes much shorter than the nearpoint of accommodation can be considered as instantaneous, assuming that the distance ( $d$ ) is 10 mm and the exposure time is 0.25 s, the classification may be determined by means of exposure dose through the limiting aperture (1 mm diameter) for the wave-length region.

Thus, for semiconductor laser light sources having a divergence angle  $\theta$ , the product of the correction factor  $\eta_\theta$  defined by the following formula and the AEL to each class (Tables 7 to 10) shall be taken as the AEL applicable to each class.

$$\eta_\theta = \frac{1}{1 - \exp[-4 \ln 2 \cdot a^2 / (d^2 \cdot \theta^2)]} \dots \dots \dots (1)$$

where  $a$ : limiting aperture

$d$ : distance between light source and eye

For  $\lambda < 1400$  nm:  $a = 3.5$  mm,  $d = 10$  cm

For  $\lambda \geq 1400$  nm:  $a = 0.5$  mm,  $d = 1$  cm

Correction factor  $\eta_\theta$  for divergence angle  $\theta$  (full angle at half maximum) is shown in Attached Fig. 16.

- (3) AEL values determined by means of the above-mentioned method are only applicable when an optical instrument (except correcting lens such as eyeglasses) is not used. In other words, they are not applicable for such a case that an eye-loupe or microscope, semiconductor lasers having lens for collimator or equipment provided with optical fiber connector having lens is used.

- Remarks 1. In the measurements of laser radiation for classification of usual laser products radiant power (W) or radiant energy (J) within a circular aperture stop not exceeding 80 mm diameter shall be measured [see 3.4.2 (6)]. This means such an assumption that the laser beam is observed by means of optical instruments such as a telescope of diameter 80 mm. The classification of semiconductor laser light sources, as prescribed in (3), is exempted from the requirement of 3.4.2 (6), provided that any optical system to reduce a divergence angle of emergent beam is not included. When optical instruments especially such as eye-lupe, microscope etc. are used, it is necessary to determine the AEL by taking such facts into consideration that the convergence factor and imaging size are related to the properties of optical equipment and light source (for instance, divergence angle, diameter of emergent beam, wavelength etc.) and a difference of viewing time (exposure duration) etc.
2. A divergence beam angle  $\theta$  of a semiconductor laser light source can not be defined universally because of large variance in laser waveguide size, but in respect to optical fiber, a divergence angle can be defined by means of its parameters. For multimode optical fiber (MMF), utilizing such a relation that the full divergence angle  $\phi(e^{-3})$  at the point where the power density becomes 5 % ( $e^{-3}$ ) of its peak value is equal to two times of the numerical aperture NA, a full angle at half maximum  $\theta$  is obtained from the following formula.

$$\theta_{\text{MMF}} = \frac{\ln 2}{3} \phi(e^{-3}) = 2 \frac{\ln 2}{3} \text{NA} \approx 0.961 \cdot \text{NA}$$

Thus, correction factor  $\eta_\theta$  is given by,

$$\eta_{\theta(\text{MMF})} = \frac{1}{1 - \exp\left(\frac{-3a^2}{(d \cdot \text{NA})^2}\right)} \dots\dots\dots (2)$$