International Standard ISO 6161

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION•МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

Personal eye-protectors — Filters and eye-protectors against laser radiation

Protecteurs individuels de l'œil — Filtres et protecteurs de l'œil contre les rayons laser

First edition — 1981-02-15

UDC 614.893 **Ref. No. ISO 6161-1981 (E)**

Descriptors : accident prevention, eyes, optical filters, safety devices, radiation protection, laser radiation, specifications, exposure, transmittance, optical properties, marking.

Price based on 4 pages

ISO 6161-1981 (E)

Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 6161 was developed by Technical Committee ISO/TC 94, *Personal safety — Protective clothing and equipment*, and was circulated to the member bodies in July 1978.

It has been approved by the member bodies of the following countries :

Australia	Iran	Poland
Austria	Israel	Romania
Belgium	Italy	South Africa, Rep of
Denmark	Mexico	Spain
France	Netherlands	Switzerland
Germany, F. R.	New Zealand	USA
Hungary	Norway	USSR

The member bodies of the following countries expressed disapproval of the document on technical grounds :

Czechoslovakia
United Kingdom

Personal eye-protectors — Filters and eye-protectors against laser radiation

0 Introduction

The work undertaken for the finalization of ISO 6161, which was staggered over several years, represents a basic study for which a majority consensus was reached at the international level. To take account of new developments and knowledge relating to lasers and of the studies undertaken within IEC/TC 76, a revision of ISO 6161 will be undertaken by the working group responsible for this work from the beginning.

1 Scope and field of application

This International Standard specifies requirements for spectacle filters and eye-protectors against laser radiation within the spectral region 0,2 to 1 000 µm.

2 References

ISO 4849, *Personal eye-protectors — Specifications.*

ISO 4854, *Personal eye-protectors — Optical test methods.*

ISO 4855, *Personal eye-protectors — Non-optical test methods.*

3 Basic considerations

In a lasing system, light is amplified by stimulated emission which produces a collimated beam of coherent electromagnetic radiation of one or more wavelengths determined by the lasing system. This characteristic radiation is of great radiant intensity and very low angular divergence. When working with lasers, personnel may therefore need to protect their eyes by filters against this radiation.

Laser filters should, especially, absorb and/or reflect a great part of the radiation of the laser wavelength to prevent any damage to the eyes. However, the transmission should be as large as possible at other wavelengths.

It is possible to produce laser radiation of many different wavelengths by choosing appropriate substances. In addition, there exist lasers which are tunable in certain wavelength ranges. Particularly dangerous are frequency-doubled lasers : in their beam the double frequency as well as the normal frequency may exist. For these reasons, it is not possible to produce only one filter type which gives sufficient protection from all kinds of lasers and laser wavelengths. Filters must therefore be used only for protection from the wavelength that is marked on them. It might even be possible that they do not give efficient protection from other wavelengths of the same laser.

Laser radiation of different spectral regions can cause different kinds of injury to the eyes :

a) Ultra-violet exposure between 200 and 380 nm produces photophobia accompanied by redness, lachrymation, conjunctival discharge, surface exfoliation and stromal haze.

b) In the spectral region from 350 to 1 400 nm, laser light can reach the retina. Since it traverses the refractive media, it becomes focused; thus, the irradiation increases considerably. Excessive exposure to radiation of this region causes above all retinal damage.

c) Between 1,4 and 1 000 µm, laser radiation traversing the various media of the eye is diminished to such an extent that the retina will be endangered only secondarily. However, injuries to the anterior parts of the eye can occur : chiefly to the cornea, the eyelid, the conjunctiva, and the skin. Since no focusing effect occurs, the permissible radiant exposure and irradiance, respectively, are considerably higher when these lasers are being used.

In these three spectral regions, the maximum permissible exposure for the eyes has been measured or calculated by different investigators. In two of these spectral regions, the maximum permissible exposure is the same. Therefore, the spectral region has been divided into two ranges :

1) 200 to 1 400 nm, where the permissible irradiance and the radiant exposure, respectively, must be very low, and

2) 1,4 to 1 000 µm, where both can be considerably higher.

The maximum permissible irradiance also depends on the duration of the laser radiation. Therefore, it is useful to distinguish whether the laser is used as a continuous-wave (CW) laser, a pulsed laser or a giant-pulse laser.

4 Spectral requirements

4.1 Spectral transmittance

The limits adopted in this International Standard correspond to the case of long exposure to CW-lasers and to the concentration of the total permissible irradiation in one pulse of a pulsed laser.

The transmittance shall be measured at an angle of incidence of 0°; for laser filters with interference layers, it shall be measured between angles of 0° and 30°, the highest of the values obtained giving the protective density.

4.1.1 Laser wavelengths from 200 to 1 400 nm

Table 1 shows respectively the maximum irradiance E and radiant exposure H (per pulse) permissible at the cornea.

Table 1 — Maximum permissible irradiance and radiant exposure

The values given in this table are guidelines.
Each country may base safety levels on its national codes until international agreement is obtained.

Laser type	Actual working time or Pulse duration	Maximum permissible irradiance* or Maximum permissible radiant exposure*
CW-laser	> 0,1 s	$E_{CW} = 5 \times 10^{-2}$ W/m²
Pulsed laser	1 µs to 0,1 s	$H_p = 5 \times 10^{-3}$ J/m²
Giant-pulse laser	1 ns to 1 µs	$H_{GP} = 5 \times 10^{-4}$ J/m²

* E_{CW} : Maximum permissible irradiance at the cornea for a CW-laser.

H_p : Maximum permissible radiant exposure at the cornea for a pulsed laser.

H_{GP} : Maximum permissible radiant exposure at the cornea for a giant-pulse laser.

Values relating to pulse durations of less than 1 ns are not yet known. Based on present knowledge, the values will have to be fixed lower than 5×10^{-4} J/m². The irradiance and the radiant exposure, respectively, are calculated from the geometry of the beam and the characteristics of the laser. The least favourable case has to be considered.

4.1.2 Laser wavelengths from 1,4 to 1 000 µm

In addition to the CO_2-laser (wavelength 10,6 µm), which is the most common, there are many other lasers which operate in the spectral region from 1,4 to 1 000 µm. In this region, the absorption by biological tissues is rather high, so that practically no radiation can reach the retina. The values of the maximum permissible irradiance and radiant exposure, respectively, in this region of the spectrum are about the same as those given for CO_2-lasers in table 2.

Table 2 — Maximum permissible irradiance and radiant exposure at 10,6 µm

The values given in this table are guidelines.
Each country may base safety levels on its national codes until international agreement is obtained.

Laser type	Actual working time or Pulse duration	Maximum permissible irradiance or Maximum permissible radiant exposure
CW-laser	> 0,1 s	$E_{CW} = 10^3$ W/m²
Pulsed laser	1 µs to 1 s	$H_p = 10^2$ J/m²

Values relating to pulse durations of less than 1 µs are as yet not well established.

4.1.3 Protective density

The protective density of a laser filter is a value derived from the common logarithm of the reciprocal of the maximum transmittance of the filter at the laser wavelength for which it is intended, taking account of the maximum irradiance or radiant exposure, as specified in table 3, which the filter will withstand. The maximum transmittance can be calculated for a given irradiance and radiant exposure, respectively, produced by a laser and due to the known maximum permissible exposure (tables 1 and 2). This is done in table 3 for the two spectral ranges 200 to 1 400 nm and 1,4 to 1 000 µm, for the different types of laser.

For pulsed lasers used with a pulse repetition rate of more than 10 s⁻¹, the appropriate protective density must be chosen from the CW-laser column.

Table 3 — Properties and use of laser filters

As the values in columns C and D are related to tables 1 and 2, they are to be considered as guidelines.
Each country may base safety levels on its national codes until international agreement is obtained.

A	B	C			D	
Protective density	Maximum spectral transmittance $\tau(\lambda)$ at the laser wavelengths	Maximum irradiance or radiant exposure which the filter will withstand				
		Spectral range 200 to 1 400 nm			Spectral range 1,4 to 1 000 µm	
		E_{CW} W/m²	H_p J/m²	H_{GP} J/m²	E_{CW} W/m²	H_p J/m²
L 1	10^{-1}	0,5	0,05	0,005	10^4	10^3
L 2	10^{-2}	5	0,5	0,05	10^5	10^4
L 3	10^{-3}	50	5	0,5	10^6	10^5
L 4	10^{-4}	5×10^2	50	5	10^7	10^6
L 5	10^{-5}	5×10^3	5×10^2	50	10^8	10^7
L 6	10^{-6}	5×10^4	5×10^3	5×10^2	10^9	10^8
L 7	10^{-7}	5×10^5	5×10^4	5×10^3	10^{10}	10^9
L 8	10^{-8}	5×10^6	5×10^5	5×10^4	—	10^{10}
L 9	10^{-9}	5×10^7	5×10^6	5×10^5	—	10^{11}
L 10	10^{-10}	5×10^8	5×10^7	5×10^6	—	—
L 11	10^{-11}	5×10^9	5×10^8	5×10^7	—	—

4.2 Luminous transmittance

With reference to the CIE standard illuminant C, the transmittance for a laser filter should be not less than 0,15. If, for technical reasons, a darker filter is to be used, the illuminance at the working place must be adequate.

4.3 Resistance to laser radiation

Filters shall not lose their protective efficiency against laser radiation under the test conditions specified below.

The filters shall be exposed to laser radiation of the maximum irradiance and radiant exposure, respectively, against which the filter is intended to protect. Test times are given in table 4.

Table 4 — Test times

Laser type	Test time
CW-laser and quasi-CW-laser as pulsed lasers with a pulse repetition rate of more than 10 s^{-1}	up to 10 exposures of 10 s
All pulsed lasers with a pulse repetition rate of less than 10 s^{-1}	up to 10 exposures of 100 pulses

During and after the first exposure, the filter shall give full protection according to its protective density. If no melting, breaking or other damage is clearly visible after the first test, the test shall be repeated up to 10 times. During and after each test, protective density shall be measured. The test shall be halted when melting, breaking or other damage is observed. The point at which either damage or loss of protective density occurs shall be reported. Loss of protective density by bleaching is unacceptable.

5 Additional requirements

5.1 Refractive properties

Except for a marginal zone of 5 mm, filters for goggles having separate eye-pieces shall not exceed the refractive values given in table 5. In the case of single filters intended for use in helmets, in hand-shields, and in goggles, these requirements apply only to each of two circular areas in the filter, both 52 mm in diameter. The two centres of the circles shall be spaced symmetrically about the centre of the filter, and the distance between them shall be 66 mm.

Table 5 — Permissible maximum refractive properties of filters

Class	Spherical effect m^{-1}	Astigmatism m^{-1}	Prismatic effect cm/m
1	± 0,06	0,06	0,12
2	± 0,12	0,12	0,25

Measurements shall be made according to the method described in ISO 4854, sub-clause 3.1.

5.2 Quality of material and surface

5.2.1 Material defects

Except for a marginal zone of 5 mm, filters for goggles having separate eye-pieces shall show no material defects such as blisters, streaks, inclusions, cloudiness, pits, mould impressions, draw lines or other defects inherent in production which would impair vision through them under conditions of use. In the case of single filters intended for use in helmets, in hand-shields, and in goggles, these requirements apply only to each of two circular areas on the filter, both 52 mm in diameter. The two centres of the circles shall be spaced symmetrically about the centre of the filter, and the distance between them shall be 66 mm.

Reflective laser filters must be protected in order to have a high mechanical and chemical resistance.

5.2.2 Scattered light

Light scattered by the filters shall not exceed 1,0 cd/(m^2.lx), when measured by the method described in ISO 4854, clause 4.

5.2.3 Induced emission

When a filter is irradiated by a laser with its maximum permissible irradiance or radiant exposure at the wavelength specified, induced emission which may be harmful to the eye shall not occur.

5.3 Filter stability

5.3.1 Stability under ultraviolet radiation

After being tested according to clause 5 of ISO 4855, or by other approved methods giving the same results, the filters shall still meet the requirements of 4.1, 4.2, 5.1 and 5.2.

5.3.2 Thermal stability

After test specimens have been stored for 5 h in a climatic test cabinet at 40 ± 1 °C and a relative humidity of at least 95 %, they shall meet the requirements of 4.1, 4.2, 5.1 and 5.2. The relative change in luminous transmittance shall be less than ± 15 %. The spectral transmittance at the laser wavelengths shall not change by more than the factor 2, and the protective density shall not be less than the value marked on the laser filter.

5.4 Flammability

When tested according to the method described in ISO 4855, sub-clause 6.1, the filters shall not ignite or continue to glow.

5.5 Construction of filters

Filter assemblies shall resist the robustness test described in ISO 4855, sub-clause 3.1.

If the filters consist of several partial filters, they shall be a sealed unit.

6 Eye-protectors

6.1 Construction

The design and assembly techniques employed by the manufacturer shall make subsequent separation and re-assembly of filters and frame difficult.

6.2 Frame

Eye-protectors shall be constructed in such a way that lateral penetration of laser light is prevented. The material shall give sufficient protection against laser radiation. The requirements of 4.1.1 and 4.1.2 also apply to the frame. For inspection and control of the resistance of eye-protectors to laser radiation, expose them respectively to the maximum irradiance and radiant exposure, against which the filter is intended to protect. The testing procedure shall be the same as in 4.3. After these tests, there shall be no holes in the eye-protectors. Complete eye-protectors shall also meet the particular requirements given in sub-clause 7.2.2 of ISO 4849.

6.3 Robustness

Eye-protectors shall resist the robustness test described in ISO 4855, sub-clause 3.2.

7 Marking

7.1 Eye-protectors

Eye-protectors shall be marked with the following information :

a) wavelength or wavelength range (in nanometres : nm) in which they protect; other metric units (for example micrometres : µm) are permissible if the unit is marked on the filter;

b) protective density;

c) symbol of the manufacturer;

d) class of refractive power.

If an eye-protector protects against radiation in one or several spectral regions, it is necessary to indicate the lowest protective density within the corresponding spectral region.

Examples : 633 L5 Q1
10,6 µm L9 T2

If an eye-protector is usable only for one type of laser, such as continuous-wave (CW), pulsed (P), or giant-pulse (GP) it shall be marked with the suffix CW, P or GP, or with two of these suffixes.

Examples : 517 L7 R2 CW
1 060 L11 S1 CW/P

Where required to do so, the manufacturer shall supply additional information together with his filters, by means of transmission curves or transmission tables and luminous transmittance.

7.2 Filters

If a filter gives protection against several wavelengths or spectral regions, only one marking, according to the examples in 7.1, is necessary for the purpose of identification.

The marking shall not impede the vision. The inscription shall be marked on the inside.

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