Directive 2006/25/EC of the European Parliament and of the Council of 5 April 2006 on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (artificial optical radiation) (19th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)

ANNEX II

Laser optical radiation

The biophysically relevant exposure values to optical radiation can be determined with the formulae below. The formulae to be used depend on the wavelength and duration of radiation emitted by the source and the results should be compared with the corresponding exposure limit values indicated in the Tables 2.2 to 2.4. More than one exposure value and corresponding exposure limit can be relevant for a given source of laser optical radiation.

Coefficients used as calculation tools within the Tables 2.2 to 2.4 are listed in Table 2.5 and corrections for repetitive exposure are listed in Table 2.6.

$$E = \frac{dP}{dA}\,[\mathrm{W\,m^{-2}}]$$

$$H = \int_0^t E(t) \times dt\,[\mathrm{J\,m^{-2}}]$$

Notes:

dP	*power* expressed in watt [W];
dA	*surface* expressed in square metres [m^2];
E (t), E	*irradiance or power density*: the radiant power incident per unit area upon a surface, generally expressed in watts per square metre [W m^{-2}]. Values of E(t), E come from measurements or may be provided by the manufacturer of the equipment;
H	*radiant exposure*: the time integral of the irradiance, expressed in joules per square metre [J m^{-2}];
t	*time, duration of the exposure*, expressed in seconds [s];
λ	*wavelength*, expressed in nanometres [nm];
γ	*limiting cone angle of* measurement *field-of-view* expressed in milliradians [mrad];
γ_m	*measurement field of view* expressed in milliradians [mrad];
α	*angular subtense of a source* expressed in milliradians [mrad];
	limiting aperture: the circular area over which irradiance and radiant exposure are *averaged*;
G	*integrated radiance*: the integral of the radiance over a given exposure time expressed as radiant energy per unit area of a radiating surface per unit solid angle of emission, in joules per square metre per steradian [J m^{-2} sr^{-1}].

Table 2.1 Radiation hazards

Wavelength [nm]λ	**Radiation range**	**Affected organ**	**Hazard**	**Exposure limit value table**
180 to 400	UV	eye	photochemical damage and thermal damage	2.2, 2.3
180 to 400	UV	skin	erythema	2.4
400 to 700	visible	eye	retinal damage	2.2
400 to 600	visible	eye	photochemical damage	2.3

400 to 700	visible	skin	thermal damage	2.4
700 to 1 400	IRA	eye	thermal damage	2.2, 2.3
700 to 1 400	IRA	skin	thermal damage	2.4
1 400 to 2 600	IRB	eye	thermal damage	2.2
2 600 to 10^6	IRC	eye	thermal damage	2.2
1 400 to 10^6	IRB, IRC	eye	thermal damage	2.3
1 400 to 10^6	IRB, IRC	skin	thermal damage	2.4

Table 2.2 Exposure limit values for laser exposure to the eye — Short exposure duration < 10 s

<table>
<tr><th colspan="2" rowspan="2">Wavelength [a] [nm]</th><th rowspan="2">Aperture</th><th colspan="7">Duration [s]</th></tr>
<tr><th>10^{-13} - 10^{-11}</th><th>10^{-11} - 10^{-9}</th><th>10^{-9} - 10^{-7}</th><th>10^{-7} - $1,8 \cdot 10^{-5}$</th><th>$1,8 \cdot 10^{-5}$ - $5 \cdot 10^{-5}$</th><th>$5 \cdot 10^{-5}$ - 10^{-3}</th><th>10^{-3} – 10^{1}</th></tr>
<tr><td>UVC</td><td>180 - 280</td><td rowspan="16">1 mm for t<0,3 s; $1,5 \cdot t^{0,375}$ for 0,3<t<10 s</td><td colspan="2" rowspan="16">$E = 3 \cdot 10^{10} \cdot$ [W m^{-2}] See note [c]</td><td colspan="5" rowspan="2">H = 30 [J m^{-2}]</td></tr>
<tr><td rowspan="14">UVB</td><td>280 - 302</td></tr>
<tr><td>303</td><td colspan="5">H = 40 [J m^{-2}]; if $t < 2,6 \cdot 10^{-9}$ then $H = 5,6 \cdot 10^{3}\, t^{0,25}$ [J m^{-2}] see note [d]</td></tr>
<tr><td>304</td><td colspan="5">H = 60 [J m^{-2}]; if $t < 1,3 \cdot 10^{-8}$ then $H = 5,6 \cdot 10^{3}\, t^{0,25}$ [J m^{-2}] see note [d]</td></tr>
<tr><td>305</td><td colspan="5">H = 100 [J m^{-2}]; if $t < 1,0 \cdot 10^{-7}$ then $H = 5,6 \cdot 10^{3}\, t^{0,25}$ [J m^{-2}] see note [d]</td></tr>
<tr><td>306</td><td colspan="5">H = 160 [J m^{-2}]; if $t < 6,7 \cdot 10^{-7}$ then $H = 5,6 \cdot 10^{3}\, t^{0,25}$ [J m^{-2}] see note [d]</td></tr>
<tr><td>307</td><td colspan="5">H = 250 [J m^{-2}]; if $t < 4,0 \cdot 10^{-6}$ then $H = 5,6 \cdot 10^{3}\, t^{0,25}$ [J m^{-2}] see note [d]</td></tr>
<tr><td>308</td><td colspan="5">H = 400 [J m^{-2}]; if $t < 2,6 \cdot 10^{-5}$ then $H = 5,6 \cdot 10^{3}\, t^{0,25}$ [J m^{-2}] see note [d]</td></tr>
<tr><td>309</td><td colspan="5">H = 630 [J m^{-2}]; if $t < 1,6 \cdot 10^{-4}$ then $H = 5,6 \cdot 10^{3}\, t^{0,25}$ [J m^{-2}] see note [d]</td></tr>
<tr><td>310</td><td colspan="5">$H = 10^{3}$ [J m^{-2}]; if $t < 1,0 \cdot 10^{-3}$ then $H = 5,6 \cdot 10^{3}\, t^{0,25}$ [J m^{-2}] see note [d]</td></tr>
<tr><td>311</td><td colspan="5">$H = 1,6 \cdot 10^{3}$ [J m^{-2}]; if $t < 6,7 \cdot 10^{-3}$ then $H = 5,6 \cdot 10^{3}\, t^{0,25}$ [J m^{-2}] see note [d]</td></tr>
<tr><td>312</td><td colspan="5">$H = 2,5 \cdot 10^{3}$ [J m^{-2}]; if $t < 4,0 \cdot 10^{-2}$ then $H = 5,6 \cdot 10^{3}\, t^{0,25}$ [J m^{-2}] see note [d]</td></tr>
<tr><td>313</td><td colspan="5">$H = 4,0 \cdot 10^{3}$ [J m^{-2}]; if $t < 2,6 \cdot 10^{-1}$ then $H = 5,6 \cdot 10^{3}\, t^{0,25}$ [J m^{-2}] see note [d]</td></tr>
<tr><td>314</td><td colspan="5">$H = 6,3 \cdot 10^{3}$ [J m^{-2}]; if $t < 1,6 \cdot 10^{0}$ then $H = 5,6 \cdot 10^{3}\, t^{0,25}$ [J m^{-2}] see note [d]</td></tr>
<tr><td>UVA</td><td>315 - 400</td><td colspan="5">$H = 5,6 \cdot 10^{3}\, t^{0,25}$ [J m^{-2}]</td></tr>
<tr><td rowspan="3">Visible& IRA</td><td>400 - 700</td><td rowspan="3">7 mm</td><td>$H = 1,5 \cdot 10^{-4}\, C_E$ [J m^{-2}]</td><td>$H = 2,7 \cdot 10^{4}\, t^{0,75}\, C_E$ [J m^{-2}]</td><td colspan="2">$H = 5 \cdot 10^{-3}\, C_E$ [J m^{-2}]</td><td colspan="3">$H = 18\, t^{0,75}\, C_E$ [J m^{-2}]</td></tr>
<tr><td>700 - 1 050</td><td>$H = 1,5 \cdot 10^{-4}\, C_A\, C_E$ [J m^{-2}]</td><td>$H=2,7 \cdot 10^{4}\, t^{0,75}\, C_A\, C_E$ [J m^{-2}]</td><td colspan="2">$H = 5 \cdot 10^{-3}\, C_A\, C_E$ [J m^{-2}]</td><td colspan="3">$H = 18 \cdot t^{0,75}\, C_A\, C_E$ [J m^{-2}]</td></tr>
<tr><td>1 050- 1 400</td><td>$H = 1,5 \cdot 10^{-3}\, C_C\, C_E$ [J m^{-2}]</td><td>$H =2,7 \cdot 10^{5}\, t^{0,75}\, C_C\, C_E$ [J m^{-2}]</td><td colspan="3">$H = 5 \cdot 10^{-2}\, C_C\, C_E$ [J m^{-2}]</td><td colspan="2">$H = 90 \cdot t^{0,75}\, C_C\, C_E$ [J m^{-2}]</td></tr>
<tr><td rowspan="4">IRB & IRC</td><td>1 400 - 1 500</td><td rowspan="4">See note [b]</td><td colspan="2">$E = 10^{12}$ [W m^{-2}] See note [c]</td><td colspan="4">$H = 10^{3}$ [J m^{-2}]</td><td>$H=5,6 \cdot 10^{3}\, t^{0,25}$ [J m^{-2}]</td></tr>
<tr><td>1 500 - 1 800</td><td colspan="2">$E = 10^{13}$ [W m^{-2}] See note [c]</td><td colspan="5">$H = 10^{4}$ [J m^{-2}]</td></tr>
<tr><td>1 800 - 2 600</td><td colspan="2">$E = 10^{12}$ [W m^{-2}] See note [c]</td><td colspan="4">$H = 10^{3}$ [J m^{-2}]</td><td>$H=5,6 \cdot 10^{3} \cdot t^{0,25}$ [J m^{-2}]</td></tr>
<tr><td>2 600 - 10^{6}</td><td colspan="2">$E = 10^{11}$ [W m^{-2}] See note [c]</td><td>H=100 [J m^{-2}]</td><td colspan="4">$H = 5,6 \cdot 10^{3} \cdot t^{0,25}$ [J m^{-2}]</td></tr>
</table>

a If the wavelength of the laser is covered by two limits, then the more restrictive applies.
b When $1\,400 \leq \lambda < 10^{5}$ nm : aperture diameter = 1 mm for t ≤ 0,3 s and $1,5\, t^{0,375}$ mm for 0,3 s < t < 10 s; when $10^{5} \leq \lambda < 10^{6}$ nm : aperture diameter = 11 mm.
c Due to lack of data at these pulse lengths, ICNIRP recommends the use of the 1 ns irradiance limits.
d The table states values for single laser pulses. In case of multiple laser pulses, then the laser pulse durations of pulses falling within an interval T_{min} (listed in table 2.6) must be added up and the resulting time value must be filled in for t in the formula: $5,6\, 10^{3}\, t^{0,25}$.

Table 2.3 Exposure limit values for laser exposure to the eye — Long exposure duration ≥ 10 s

Wavelength [a] [nm]		Aperture	Duration [s]		
			10^1 - 10^2	10^2 - 10^4	10^4 - $3 \cdot 10^4$
UVC	180 - 280	3,5 mm	$H = 30$ [J m^{-2}]		
UVB	280 - 302				
	303		$H = 40$ [J m^{-2}]		
	304		$H = 60$ [J m^{-2}]		
	305		$H = 100$ [J m^{-2}]		
	306		$H = 160$ [J m^{-2}]		
	307		$H = 250$ [J m^{-2}]		
	308		$H = 400$ [J m^{-2}]		
	309		$H = 630$ [J m^{-2}]		
	310		$H = 1,0 \cdot 10^3$ [J m^{-2}]		
	311		$H = 1,6 \cdot 10^3$ [J m^{-2}]		
	312		$H = 2,5 \cdot 10^3$ [J m^{-2}]		
	313		$H = 4,0 \cdot 10^3$ [J m^{-2}]		
	314		$H = 6,3 \cdot 10^3$ [J m^{-2}]		
UVA	315 - 400		$H = 10^4$ [J m^{-2}]		
Visible 400 – 700	400 - 600 Photochemical [b] Retinal damage	7 mm	$H = 100\ C_B$ [J m^{-2}] ($\gamma = 11$ mrad) [d]	$E = 1\ C_B$ [W m^{-2}]; ($\gamma = 1,1\ t^{0,5}$ mrad) [d]	$E = 1\ C_B$ [W m^{-2}] ($\gamma = 110$ mrad) [d]
	400 - 700 Thermal [b] Retinal damage		if $\alpha < 1,5$ mrad then $E = 10$ [W m^{-2}] if $\alpha > 1,5$ mrad and $t \leq T_2$ then $H = 18\ C_E\ t^{0,75}$ [J m^{-2}] if $\alpha > 1,5$ mrad and $t > T_2$ then $E = 18\ C_E\ T_2^{-0,25}$ [W m^{-2}]		
IRA	700 - 1 400	7 mm	if $\alpha < 1,5$ mrad then $E = 10\ C_A\ C_C$ [W m^{-2}] if $\alpha > 1,5$ mrad and $t \leq T_2$ then $H = 18\ C_A\ C_C\ C_E\ t^{0,75}$ [J m^{-2}] if $\alpha > 1,5$ mrad and $t > T_2$ then $E = 18\ C_A\ C_C\ C_E\ T_2^{-0,25}$ [W m^{-2}] (not to exceed 1 000 W m^{-2})		
IRB & IRC	1 400 - 10^6	See [c]	$E = 1\ 000$ [W m^{-2}]		

a If the wavelength or another condition of the laser is covered by two limits, then the more restrictive applies.

b For small sources subtending an angle of 1,5 mrad or less, the visible dual limits E from 400 nm to 600 nm reduce to the thermal limits for 10 s≤ t<T_1 and to photochemical limits for longer times. For T_1 and T_2 see Table 2.5. The photochemical retinal hazard limit may also be expressed as a time integrated radiance $G = 10^6\ C_B$ [J m^{-2} sr^{-1}] for t > 10s up to t = 10 000 s and $L = 100\ C_B$ [W m^{-2} sr^{-1}] for t > 10 000 s. For the measurement of G and L γ_m must be used as averaging field of view. The official border between visible and infrared is 780 nm as defined by the CIE. The column with wavelength band names is only meant to provide better overview for the user. (The notation G is used by CEN; the notation L_t is used by CIE; the notation L_P is used by IEC and CENELEC.)

c For wavelength 1 400 - 10^5 nm : aperture diameter = 3,5 mm; for wavelength 10^5 - 10^6 nm: aperture Diameter = 11 mm.

d For measurement of the exposure value the consideration of γ is defined as follows: If α (angular subtense of a source) > γ (limiting cone angle, indicated in brackets in the corresponding column) then the measurement field of view γ_m should be the given value of γ. (If a larger measurement field of view is used, then the hazard would be overestimated).
If α < γ then the measurement field of view γ_m must be large enough to fully enclose the source but is otherwise not limited and may be larger than γ.

Table 2.4 Exposure limit values for laser exposure of skin

Wavelength [a] [nm]		Aperture	Duration [s]					
			$< 10^{-9}$	10^{-9} - 10^{-7}	10^{-7} - 10^{-3}	10^{-3} – 10^1	10^1 - 10^3	10^3 - $3 \cdot 10^4$
UV (A, B, C)	180-400	3, 5mm	$E = 3 \cdot 10^{10}$ [W m^{-2}]	Same as eye exposure limits				
Visible and IRA	400-700	3, 5mm	$E = 2 \cdot 10^{11}$ [W m^{-2}]	$H=200\ C_A$ [J m^{-2}]	$H = 1,1 \cdot 10^4\ C_A\ t^{0,25}$ [J m^{-2}]		$E = 2 \cdot 10^3\ C_A$ [W m^{-2}]	
	700 -1 400		$E = 2 \cdot 10^{11}\ C_A$ [W m^{-2}]					
IRB and IRC	1 400-1 500		$E = 10^{12}$ [W m^{-2}]	Same as eye exposure limits				
	1 500-1 800		$E = 10^{13}$ [W m^{-2}]					
	1 800-2 600		$E = 10^{12}$ [W m^{-2}]					
	2 600-10^6		$E = 10^{11}$ [W m^{-2}]					

a If the wavelength or another condition of the laser is covered by two limits, then the more restrictive applies.

Table 2.5 Applied correction factors and other calculation parameters

Parameter as listed in ICNIRP	Valid spectral range (nm)	Value
C_A	λ < 700	$C_A = 1,0$
	700 — 1 050	$C_A = 10^{0,002(\lambda - 700)}$
	1 050 — 1 400	$C_A = 5,0$
C_B	400 — 450	$C_B = 1,0$
	450 — 700	$C_B = 10^{0,02(\lambda - 450)}$

C_C	700 — 1 150	$C_C = 1,0$
	1 150 — 1 200	$C_C = 10^{0,018(\lambda - 1\,150)}$
	1 200 — 1 400	$C_C = 8,0$
T_1	$\lambda < 450$	$T_1 = 10$ s
	450 — 500	$T_1 = 10 \cdot [10^{0,02\,(\lambda - 450)}]$ s
	$\lambda > 500$	$T_1 = 100$ s

Parameter as listed in ICNIRP	**Valid for biological effect**	**Value**
α_{min}	all thermal effects	$\alpha_{min} = 1,5$ mrad

Parameter as listed in ICNIRP	**Valid angular range (mrad)**	**Value**
C_E	$\alpha < \alpha_{min}$	$C_E = 1,0$
	$\alpha_{min} < \alpha < 100$	$C_E = \alpha/\alpha_{min}$
	$\alpha > 100$	$C_E = \alpha^2/(\alpha_{min} \cdot \alpha_{max})$ mrad with $\alpha_{max} = 100$ mrad
T_2	$\alpha < 1,5$	$T_2 = 10$ s
	$1,5 < \alpha < 100$	$T_2 = 10 \cdot [10^{(\alpha - 1,5)\,/\,98,5}]$ s
	$\alpha > 100$	$T_2 = 100$ s

Parameter as listed in ICNIRP	**Valid exposure time range (s)**	**Value**
γ	$t \leq 100$	$\gamma = 11$ [mrad]
	$100 < t < 10^4$	$\gamma = 1,1\ t^{0,5}$ [mrad]
	$t > 10^4$	$\gamma = 110$ [mrad]

Table 2.6 Correction for repetitive exposure

Each of the following three general rules should be applied to all repetitive exposures as occur from repetitively pulsed or scanning laser systems:

1. The exposure from any single pulse in a train of pulses shall not exceed the exposure limit value for a single pulse of that pulse duration.
2. The exposure from any group of pulses (or sub-group of pulses in a train) delivered in time t shall not exceed the exposure limit value for time t.
3. The exposure from any single pulse within a group of pulses shall not exceed the single-pulse exposure limit value multiplied by a cumulative-thermal correction factor $C_p=N^{-0,25}$, where N is the number of pulses. This rule applies only to exposure limits to

protect against thermal injury, where all pulses delivered in less than T_{min} are treated as a single pulse.

Parameter	**Valid spectral range (nm)**	**Value**
T_{min}	$315 < \lambda \leq 400$	$T_{min} = 10^{-9}$ s (= 1 ns)
	$400 < \lambda \leq 1\,050$	$T_{min} = 18 \cdot 10^{-6}$ s (= 18 µs)
	$1\,050 < \lambda \leq 1\,400$	$T_{min} = 50 \cdot 10^{-6}$ s (= 50 µs)
	$1\,400 < \lambda \leq 1\,500$	$T_{min} = 10^{-3}$ s (= 1 ms)
	$1\,500 < \lambda \leq 1\,800$	$T_{min} = 10$ s
	$1\,800 < \lambda \leq 2\,600$	$T_{min} = 10^{-3}$ s (= 1 ms)
	$2\,600 < \lambda \leq 10^{6}$	$T_{min} = 10^{-7}$ s (= 100 ns)