Subsidiary Legislation made under s.58.

Factories (Protection of Workers from Physical Agents) (Artificial Optical Radiation) Regulations 2010

LN. 2010/131

Commencement **29.7.2010**

Transposing:
Directive 2006/25/EC

ARRANGEMENT OF REGULATIONS

Regulation

In exercise of the powers conferred upon him by section 58 of the Factories Act, and all other enabling powers, and in order to transpose into the law of Gibraltar 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), the Minister has made the following Regulations–

Title and commencement.

1. These Regulations may be cited as the Factories (Protection of Workers from Physical Agents) (Artificial Optical Radiation) Regulations 2010 and come into operation on the day of publication.

Interpretation.

2.(1) In these Regulations–

"artificial optical radiation" means any electromagnetic radiation in the wavelength range between 100nm and 1mm which is emitted by non-natural sources;

"the Directive" means 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), as the same may be amended from time to time;

"the exposure limit values" means–

(a) for non-coherent radiation, those exposure limit values, other than that emitted by natural sources of optical radiation, set out in Annex I to the Directive (which is reproduced for information purposes in the Schedule); and

(b) for laser radiation those exposure limit values set out in Annex II to the Directive (which is reproduced for information purposes in the Schedule);

"health surveillance" means assessment of the state of health of an employee, as related to exposure to artificial optical radiation and its effects on the eyes and skin;

"inspector" means a factory inspector appointed under section 77 of the Factories Act;

"irradiance" and "E" means the radiant power incident per unit area upon a surface expressed in watts per square metre ($W\ m^{-2}$);

"laser" (light amplification by stimulated emission of radiation) means any device which can be made to produce or amplify electromagnetic radiation in the optical radiation wavelength range primarily by the process of controlled stimulated emission;

"laser radiation" means artificial optical radiation from a laser;

"level" means the combination of irradiance, radiant exposure and radiance to which an employee is exposed;

"non-coherent radiation" means any artificial optical radiation other than laser radiation;

"radiance" or "L" means the radiant flux or power output per unit solid angle per unit area expressed in watts per square metre per steradian ($W\ m^{-2}\ sr^{-1}$);

"radiant exposure" or "H" means the time integral of the irradiance, expressed in joules per square metre ($J\ m^{-2}$); and

"risk assessment" means the assessment made pursuant to regulation 7 of the Management of Health and Safety at Work Regulations, 1996.

(2) Other expressions used in these Regulations which are used in the Directive have the same meaning in these Regulations as they have in the Directive.

(3) A reference to an employee being exposed to artificial optical radiation is a reference to that exposure which arises while the employee is at work, or arises out of, or in connection with, the employee's work.

Application of these Regulations.

3. Where a duty is placed by these Regulations on an employer in respect of its employees, the employer must, so far as is reasonably practicable, be under a like duty in respect of any other person at work who may be affected by the work carried out by the employer except that the duties of the employer–

(a) under regulation 6 (information and training) do not extend to persons who are not its employees, unless those persons are present in the workplace where the work is being carried out; and

(b) under regulation 8 (health surveillance) do not extend to persons who are not its employees.

Assessment of the risk of adverse health effects to the eyes or skin created by exposure to artificial optical radiation at the workplace.

4.(1) Where–

(a) the employer carries out work which could expose any of its employees to levels of artificial optical radiation that could create a reasonably foreseeable risk of adverse health effects to the eyes or skin of the employee; and

(b) that employer has not implemented any measures to either eliminate or, where this is not reasonably practicable, reduce to as low a level as is reasonably practicable, that risk based on the general principles of prevention set out in the Schedule to the Management of Health and Safety at Work Regulations, 1996,

the employer must make a suitable and sufficient assessment of that risk for the purpose of identifying and putting into effect the measures it needs to take to meet the requirements of these Regulations, and the risk assessment shall be carried out at suitable intervals by a person appointed by the employer under regulation 10 of the Health and Safety at Work Regulations 1996 (a competent person).

(2) The employer must as part of that risk assessment assess, and if necessary, measure or calculate, the levels of artificial optical radiation to which employees are likely to be exposed.

(3) In carrying out the assessment, measurement or calculation, the employer must follow the following standards or recommendations–

(a) for laser radiation, the standards of the IEC; or

(b) for non-coherent radiation, the recommendations of the CIE and the CEN.

(4) An assessment in relation to exposures to laser radiation or non-coherent radiation may take account of the data provided by the manufacturers of the equipment when that equipment is covered by relevant European Union Directives.

(5) In exposure situations which are not covered by the standards or recommendations referred to in subregulation (3), the assessment, measurement or calculation must, until such time as appropriate EU standards or recommendations become available, follow national or international science-based guidelines.

(6) The assessment must also include consideration of–

(a) the level, wavelength range and duration of exposure;

(b) the exposure limit values;

(c) the effects of exposure on employees or groups of employees whose health is at particular risk from exposure;

(d) any possible effects on the health and safety of employees resulting from interactions between artificial optical radiation and photosensitising chemical substances;

(e) any indirect effects of exposure on the health and safety of employees such as temporary blinding, explosion or fire;

(f) the existence of alternative equipment designed to reduce levels of exposure;

(g) appropriate information obtained from health surveillance, including, where possible, published information;

(h) multiple sources of exposure;

(i) any class 3B or 4 laser that is classified in accordance with the relevant IEC standard that is in use by the employer and any artificial optical radiation source that is capable of presenting the same level of hazard; and

(j) information provided by the manufacturers of artificial optical radiation sources and associated work equipment in accordance with the relevant European Union Directives.

(7) A risk assessment may include a justification by the employer that the nature and extent of the risk of adverse health effects to the eyes and skin of employees as a result of exposure to artificial optical radiation is such that any further risk assessment is unnecessary.

(8) An employer may not rely on the justification permitted under subregulation (7) or on an existing risk assessment where–

(a) there is reason to suspect that the risk assessment is no longer valid; or

(b) there has been a significant change in the work to which the assessment relates.

(9) The employer must maintain a record in a durable format of–

(a) the significant findings of the risk assessment as soon as is practicable after it is made or changed; and

(b) the measures which have been taken and which the employer intends to take to meet the requirements of regulations 5 and 6.

(10) In subregulations (3), (5) and (6)–

(a) a reference to standards or recommendations is a reference to standards or recommendations as revised or re-issued from time to time;

(b) "CEN" means the European Committee for Standardisation;

(c) "CIE" means the International Commission on Illumination; and

(d) "IEC" means the International Electrotechnical Commission.

(11) In subregulation (6)(a) "level" means the combination of irradiance, radiant exposure and radiance to which an employee is exposed.

Obligations to eliminate or reduce risks.

5.(1) An employer must ensure that any risk of adverse health effects to the eyes or skin of employees as a result of exposure to artificial optical radiation which is identified in the risk assessment is eliminated or, where this is not reasonably practicable, reduced to as low a level as is reasonably practicable.

(2) For the purposes of subregulation (1) measures to eliminate or reduce the risk must be based on the general principles of prevention set out in the Schedule to the Management of Health and Safety at Work Regulations, 1996.

(3) If the risk assessment indicates that employees are exposed to levels of artificial optical radiation which exceed the exposure limit values, the employer must devise and implement an action plan comprising technical and organisational measures designed to prevent exposure exceeding the exposure limit values.

(4) The action plan must take into account–

(a) other working methods that reduce the risk from artificial optical radiation ;

(b) choice of appropriate work equipment emitting less artificial optical radiation;

(c) technical measures to reduce the emission of artificial optical radiation including, where necessary, the use of interlocks, shielding or similar health protection mechanisms;

(d) appropriate maintenance programmes for work equipment, workplaces and workstation systems;

(e) the design and layout of workplaces and workstations;

(f) limitation of the duration and level of the exposure;

(g) the availability of appropriate personal protective equipment;

(h) the instructions of the manufacturer of the equipment where it is covered by relevant European Union Directives.

(5) If, despite the measures taken under subregulations (1) and (3), employees are still exposed to levels of artificial optical radiation that exceed the exposure limit values, the employer must take immediate action to–

(a) reduce exposure to below the exposure limit values;

(b) identify the reasons why employees have been exposed to levels which exceed the exposure limit values; and

(c) modify the measures taken in accordance with subregulation (3) to prevent employees being exposed again to levels which exceed the exposure limit values.

(6) Subregulation (7) applies if the risk assessment indicates that in any of the areas of the workplace under the control of the employer, employees could be exposed to levels of artificial optical radiation which exceed the exposure limit values.

(7) The employer must ensure that the areas in question are–

(a) demarcated and access by the employees to those areas is restricted so far as is reasonably practicable; and

(b) identified by means of the appropriate signs as specified in the Health and Safety (Safety Signs and Signals) Regulations 1996.

(8) When discharging a duty imposed on it by this regulation an employer, shall make such adaptations as are required to meet the requirements of employees belonging to particularly sensitive groups.

Information and training.

6.(1) If the risk assessment indicates that employees could be exposed to artificial optical radiation which could cause adverse health effects to the eyes or skin of employees, the employer must provide its employees, their representatives or both, with suitable and sufficient information and training relating to the outcome of the risk assessment, and this must include the following–

(a) the technical and organisational measures taken in order to comply with the requirements of regulation 5;

(b) the exposure limit values and the associated potential risks;

(c) the findings of the risk assessment, including any measurements taken or calculations made of the levels of exposure, with an explanation of their significance and potential risks;

(d) how to detect and report adverse health effects of exposure;

(e) the circumstances in which employees are entitled to health surveillance;

(f) safe working practices to minimise the risk of adverse health effects to the eyes or skin from exposure to artificial optical radiation; and

(g) the proper use of personal protective equipment.

(2) The employer must ensure that any person, whether or not that person is an employee, who carries out work in connection with the employer's duties under these Regulations has suitable and sufficient information and training.

Consultation and participation.

7. The consultation and participation of employees in matters arising from the application of these Regulations shall be conducted in accordance with regulation 8 of the Management of Health and Safety at Work Regulations 1996.

Health surveillance and medical examinations.

8.(1) If the risk assessment indicates that there is a risk of adverse health effects to the eyes or skin of employees as a result of exposure to artificial optical radiation, the employer must ensure that such employees are placed under suitable health surveillance.

(2) Health surveillance pursuant to subregulation (1) must be carried out by a doctor or occupational health professional and the risk assessment must be made available to that doctor or occupational health professional.

(3) The employer must ensure that a health record of each of its employees who undergoes health surveillance pursuant to subregulation (1) is made and maintained and that the record contains a summary of the results of the health surveillance carried out and is kept in a suitable form so as to permit any consultation at a later date, taking into account any confidentiality

(4) The employer must–

(a) on reasonable notice being given, allow an employee access to his personal health record; and

(b) provide an inspector with copies of such health records as he may require.

(5) An employer must ensure that a medical examination of the employee is carried out where–

(a) the employee has been exposed to levels of artificial optical radiation which exceed the exposure limit values; or

(b) as a result of health surveillance the employee is found to have an identifiable disease or adverse health effects to the eyes or skin which is considered by a doctor or occupational health professional to be the result of exposure to artificial optical radiation.

(6) Where an examination is carried out under subregulation (5), the employer must–

(a) ensure that a doctor or suitably qualified person–

(i) informs the employee of the results of the examination which relate to him; and

(ii) provides advice on whether health surveillance may be appropriate;

(b) ensure that it is informed of any significant findings from any health surveillance of the employee taking into account any medical confidentiality;

(c) review the risk assessment;

(d) review any measures taken to comply with regulation 5 taking into account any advice given by a doctor or other suitably qualified person or an inspector; and

(e) provide continued health surveillance and provide for a review of the health status of any other employee who has been similarly exposed.

SCHEDULE

Regulation 2(1)

This Schedule reproduces Annexes I and II of the Directive

ANNEX I
Non-coherent 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 range of radiation emitted by the source and the results should be compared with the corresponding exposure limit values indicated in Table 1.1. More than one exposure value and corresponding exposure limit can be relevant for a given source of optical radiation.

Numbering (a) to (o) refers to corresponding rows of Table 1.1.

(a)	$H_{eff} = \int_0^t \int_{\lambda = 180\ nm}^{\lambda = 400\ nm} E_\lambda(\lambda, t) \cdot S(\lambda) \cdot d\lambda \cdot dt$	(H_{eff} is only relevant in the range 180 to 400 nm)
(b)	$H_{UVA} = \int_0^t \int_{\lambda = 315\ nm}^{\lambda = 400\ nm} E_\lambda(\lambda, t) \cdot d\lambda \cdot dt$	(H_{UVA} is only relevant in the range 315 to 400 nm)
(c), (d)	$L_B = \int_{\lambda = 300\ nm}^{\lambda = 700\ nm} L_\lambda(\lambda) \cdot B(\lambda) \cdot d\lambda$	(L_B is only relevant in the range 300 to 700 nm)
(e), (f)	$E_B = \int_{\lambda = 300\ nm}^{\lambda = 700\ nm} E_\lambda(\lambda) \cdot B(\lambda) \cdot d\lambda$	(E_B is only relevant in the range 300 to 700 nm)
(g) to (l)	$L_R = \int_{\lambda_1}^{\lambda_2} L_\lambda(\lambda) \cdot R(\lambda) \cdot d\lambda$	(See Table 1.1 for appropriate values of λ_1 and λ_2)
(m), (n)	$E_{IR} = \int_{\lambda = 780\ nm}^{\lambda = 3000\ nm} E_\lambda(\lambda) \cdot d\lambda$	(E_{IR} is only relevant in the range 780 to 3 000 nm)
(o)	$H_{skin} = \int_0^t \int_{\lambda = 380\ nm}^{\lambda = 3000\ nm} E_\lambda(\lambda, t) \cdot d\lambda \cdot dt$	(H_{skin} is only relevant in the range 380 to 3 000 nm)

For the purposes of this Directive, the formulae above can be replaced by the following expressions and the use of discrete values as set out in the following tables:

(a) $E_{eff} = \sum_{\lambda = 180\ nm}^{\lambda = 400\ nm} E_\lambda \cdot S(\lambda) \cdot \Delta\lambda$ and $H_{eff} = E_{eff} \cdot \Delta t$

(b) $E_{UVA} = \sum_{\lambda = 315\ nm}^{\lambda = 400\ nm} E_\lambda \cdot \Delta\lambda$ and $H_{UVA} = E_{UVA} \cdot \Delta t$

(c), (d) $L_B = \sum_{\lambda = 300\ nm}^{\lambda = 700\ nm} L_\lambda \cdot B(\lambda) \cdot \Delta\lambda$

(e), (f) $E_B = \sum_{\lambda = 300\ nm}^{\lambda = 700\ nm} E_\lambda \cdot B(\lambda) \cdot \Delta\lambda$

(g) to (l) $L_R = \sum_{\lambda_1}^{\lambda_2} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda$ (See Table 1.1 for appropriate values of λ_1 and λ_2)

(m), (n) $E_{IR} = \sum_{\lambda = 780\ nm}^{\lambda = 3\,000\ nm} E_\lambda \cdot \Delta\lambda$

(o) $E_{skin} = \sum_{\lambda = 380\ nm}^{\lambda = 3\,000\ nm} E_\lambda \cdot \Delta\lambda$ and $H_{skin} = E_{skin} \cdot \Delta t$

Notes:

$E_\lambda(\lambda,t)$, E_λ	*spectral irradiance or spectral power density*: the radiant power incident per unit area upon a surface, expressed in watts per square metre per nanometre [$W\ m^{-2}\ nm^{-1}$]; values of $E_\lambda(\lambda, t)$ and E_λ come from measurements or may be provided by the manufacturer of the equipment;
E_{eff}	*effective irradiance (UV range)*: calculated irradiance within the UV wavelength range 180 to 400 nm spectrally weighted by $S(\lambda)$, expressed in watts per square metre [$W\ m^{-2}$];
H	*radiant exposure*: the time integral of the irradiance, expressed in joules per square metre [$J\ m^{-2}$];
H_{eff}	*effective radiant exposure*: radiant exposure spectrally weighted by $S(\lambda)$, expressed in joules per square metre [$J\ m^{-2}$];
E_{UVA}	*total irradiance (UVA)*: calculated irradiance within the UVA wavelength range 315 to 400 nm, expressed in watts per square metre [$W\ m^{-2}$];
H_{UVA}	*radiant exposure*: the time and wavelength integral or sum of the irradiance within the UVA wavelength range 315 to 400 nm, expressed in joules per square metre [$J\ m^{-2}$];
$S(\lambda)$	*spectral weighting* taking into account the wavelength dependence of the health effects of UV radiation on eye and skin, (Table 1.2) [dimensionless];
t, Δt	*time, duration of the exposure*, expressed in seconds [s];
λ	*wavelength*, expressed in nanometres [nm];
$\Delta\lambda$	*bandwidth*, expressed in nanometres [nm], of the calculation or measurement intervals;
$L_\lambda(\lambda)$, L_λ	*spectral radiance of the source* expressed in watts per square metre per steradian per nanometre [$W\ m^{-2}\ sr^{-1}\ nm^{-1}$];
$R(\lambda)$	*spectral weighting* taking into account the wavelength dependence of the thermal injury caused to the eye by visible and IRA radiation (Table 1.3) [dimensionless];
L_R	*effective radiance (thermal injury)*: calculated radiance spectrally weighted by $R(\lambda)$ expressed in watts per square metre per steradian [$W\ m^{-2}\ sr^{-1}$];
$B(\lambda)$	*spectral weighting* taking into account the wavelength dependence of the photochemical injury caused to the eye by blue light radiation (Table 1.3) [dimensionless];
L_B	*effective radiance (blue light)*: calculated radiance spectrally weighted by $B(\lambda)$, expressed in watts per square metre per steradian [$W\ m^{-2}\ sr^{-1}$];
E_B	*effective irradiance (blue light)*: calculated irradiance spectrally weighted by $B(\lambda)$ expressed in watts per square metre [$W\ m^{-2}$];
E_{IR}	*total irradiance (thermal injury)*: calculated irradiance within the infrared wavelength range 780 nm to 3 000 nm expressed in watts per square metre [$W\ m^{-2}$];
E_{skin}	*total irradiance (visible, IRA and IRB)*: calculated irradiance within the visible and infrared wavelength range 380 nm to 3 000 nm, expressed in watts per square metre [$W\ m^{-2}$];
H_{skin}	*radiant exposure*: the time and wavelength integral or sum of the irradiance within the visible and infrared wavelength range 380 to 3 000 nm, expressed in joules per square metre ($J\ m^{-2}$);
α	*angular subtense*: the angle subtended by an apparent source, as viewed at a point in space, expressed in milliradians (mrad). Apparent source is the real or virtual object that forms the smallest possible retinal image.

Table 1.1

Exposure limit values for non-coherent optical radiation

Index	Wavelength nm
a.	180-400 (UVA, UVB and UVC)
b.	315-400 (UVA)
c.	300-700 (Blue light) *see note 1*
d.	300-700 (Blue light) *see note 1*
e.	300-700 (Blue light) *see note 1*
f.	300-700 (Blue light) *see note 1*

Index	Wavelength nm	Exposure limit value	Units	Comment	Part of the body	Hazard
g.	380-1 400 (Visible and IRA)	$L_R = \frac{2,8 \cdot 10^7}{C_\alpha}$ for t >10 s	[W m^{-2} sr^{-1}]	C_α = 1,7 for α ≤ 1,7 mrad C_α = α for 1,7 ≤ α ≤ 100 mrad C_α = 100 for α > 100 mrad λ_1 = 380; λ_2 = 1 400	eye retina	retinal burn
h.	380-1 400 (Visible and IRA)	$L_R = \frac{5 \cdot 10^7}{C_\alpha t^{0,25}}$ for 10 µs ≤ t ≤ 10 s	L_R:[W m^{-2} sr^{-1}] t: [seconds]			
i.	380-1 400 (Visible and IRA)	$L_R = \frac{8,89 \cdot 10^8}{C_\alpha}$ for t <10 µs	[W m^{-2} sr^{-1}]			
j.	780-1 400 (IRA)	$L_R = \frac{6 \cdot 10^6}{C_\alpha}$ for t > 10 s	[W m^{-2} sr^{-1}]	C_α = 11 for α ≤ 11 mrad C_α = α for 11≤ α ≤ 100 mrad C_α = 100 for α > 100 mrad (measurement field-of-view: 11 mrad) λ_1 = 780; λ_2 = 1 400	eye retina	retinal burn
k.	780-1 400 (IRA)	$L_R = \frac{5 \cdot 10^7}{C_\alpha t^{0,25}}$ for 10 µs ≤ t ≤ 10 s	L_R: [W m^{-2} sr^{-1}] t: [seconds]			
l.	780-1 400 (IRA)	$L_R = \frac{8,89 \cdot 10^8}{C_\alpha}$ for t < 10 µs	[W m^{-2} sr^{-1}]			
m.	780-3 000 (IRA and IRB)	E_{IR} = 18 000 $t^{-0,75}$ for t ≤ 1 000 s	E: [W m^{-2}] t: [seconds]		eye cornea lens	corneal burn cataractogenesis
n.	780-3 000 (IRA and IRB)	E_{IR} = 100 for t > 1 000 s	[W m^{-2}]			

Index	Wavelength nm	Exposure limit value	Units	Comment	Part of the body	Hazard
o.	380-3 000 (Visible, IRA and IRB)	$H_{skin} = 20\ 000\ t^{0,25}$ for $t < 10$ s	H: [J m^{-2}] t: [seconds]		skin	burn

Note 1: The range of 300 to 700 nm covers parts of UVB, all UVA and most of visible radiation; however, the associated hazard is commonly referred to as '*blue light*' hazard. Blue light strictly speaking covers only the range of approximately 400 to 490 nm.

Note 2: For steady fixation of very small sources with an angular subtense < 11 mrad, L_B can be converted to E_B. This normally applies only for ophthalmic instruments or a stabilized eye during anaesthesia. The maximum 'stare time' is found by: $t_{max} = 100/E_B$ with E_B expressed in W m^{-2}. Due to eye movements during normal visual tasks this does not exceed 100 s.

Table 1.2

S (λ) [dimensionless], 180 nm to 400 nm

λ in nm	S (λ)	λ in nm	S (λ)	λ in nm	S (λ)	λ in nm	S (λ)	λ in nm	S (λ)
180	0,0120	228	0,1737	276	0,9434	324	0,000520	372	0,000086
181	0,0126	229	0,1819	277	0,9272	325	0,000500	373	0,000083
182	0,0132	230	0,1900	278	0,9112	326	0,000479	374	0,000080
183	0,0138	231	0,1995	279	0,8954	327	0,000459	375	0,000077
184	0,0144	232	0,2089	280	0,8800	328	0,000440	376	0,000074
185	0,0151	233	0,2188	281	0,8568	329	0,000425	377	0,000072
186	0,0158	234	0,2292	282	0,8342	330	0,000410	378	0,000069
187	0,0166	235	0,2400	283	0,8122	331	0,000396	379	0,000066
188	0,0173	236	0,2510	284	0,7908	332	0,000383	380	0,000064
189	0,0181	237	0,2624	285	0,7700	333	0,000370	381	0,000062
190	0,0190	238	0,2744	286	0,7420	334	0,000355	382	0,000059
191	0,0199	239	0,2869	287	0,7151	335	0,000340	383	0,000057
192	0,0208	240	0,3000	288	0,6891	336	0,000327	384	0,000055
193	0,0218	241	0,3111	289	0,6641	337	0,000315	385	0,000053
194	0,0228	242	0,3227	290	0,6400	338	0,000303	386	0,000051
195	0,0239	243	0,3347	291	0,6186	339	0,000291	387	0,000049
196	0,0250	244	0,3471	292	0,5980	340	0,000280	388	0,000047
197	0,0262	245	0,3600	293	0,5780	341	0,000271	389	0,000046
198	0,0274	246	0,3730	294	0,5587	342	0,000263	390	0,000044
199	0,0287	247	0,3865	295	0,5400	343	0,000255	391	0,000042
200	0,0300	248	0,4005	296	0,4984	344	0,000248	392	0,000041
201	0,0334	249	0,4150	297	0,4600	345	0,000240	393	0,000039
202	0,0371	250	0,4300	298	0,3989	346	0,000231	394	0,000037
203	0,0412	251	0,4465	299	0,3459	347	0,000223	395	0,000036
204	0,0459	252	0,4637	300	0,3000	348	0,000215	396	0,000035
205	0,0510	253	0,4815	301	0,2210	349	0,000207	397	0,000033
206	0,0551	254	0,5000	302	0,1629	350	0,000200	398	0,000032
207	0,0595	255	0,5200	303	0,1200	351	0,000191	399	0,000031
208	0,0643	256	0,5437	304	0,0849	352	0,000183	400	0,000030
209	0,0694	257	0,5685	305	0,0600	353	0,000175		
210	0,0750	258	0,5945	306	0,0454	354	0,000167		
211	0,0786	259	0,6216	307	0,0344	355	0,000160		
212	0,0824	260	0,6500	308	0,0260	356	0,000153		
213	0,0864	261	0,6792	309	0,0197	357	0,000147		
214	0,0906	262	0,7098	310	0,0150	358	0,000141		
215	0,0950	263	0,7417	311	0,0111	359	0,000136		
216	0,0995	264	0,7751	312	0,0081	360	0,000130		
217	0,1043	265	0,8100	313	0,0060	361	0,000126		
218	0,1093	266	0,8449	314	0,0042	362	0,000122		
219	0,1145	267	0,8812	315	0,0030	363	0,000118		
220	0,1200	268	0,9192	316	0,0024	364	0,000114		
221	0,1257	269	0,9587	317	0,0020	365	0,000110		
222	0,1316	270	1,0000	318	0,0016	366	0,000106		
223	0,1378	271	0,9919	319	0,0012	367	0,000103		
224	0,1444	272	0,9838	320	0,0010	368	0,000099		
225	0,1500	273	0,9758	321	0,000819	369	0,000096		
226	0,1583	274	0,9679	322	0,000670	370	0,000093		
227	0,1658	275	0,9600	323	0,000540	371	0,000090		

Table 1.3

B (λ), R (λ) [dimensionless], 380 nm to 1 400 nm

λ in nm	B (λ)	R (λ)
$300 \leq \lambda < 380$	0,01	—
380	0,01	0,1
385	0,013	0,13
390	0,025	0,25
395	0,05	0,5
400	0,1	1
405	0,2	2
410	0,4	4
415	0,8	8
420	0,9	9
425	0,95	9,5
430	0,98	9,8
435	1	10
440	1	10
445	0,97	9,7
450	0,94	9,4
455	0,9	9
460	0,8	8
465	0,7	7
470	0,62	6,2
475	0,55	5,5
480	0,45	4,5
485	0,32	3,2
490	0,22	2,2
495	0,16	1,6
500	0,1	1
$500 < \lambda \leq 600$	$10^{0,02 \cdot (450 - \lambda)}$	1
$600 < \lambda \leq 700$	0,001	1
$700 < \lambda \leq 1\,050$	—	$10^{0,002 \cdot (700 - \lambda)}$
$1\,050 < \lambda \leq 1\,150$	—	0,2
$1\,150 < \lambda \leq 1\,200$	—	$0,2 \cdot 10^{0,02 \cdot (1\,150 - \lambda)}$
$1\,200 < \lambda \leq 1\,400$	—	0,02

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 so urce 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.

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

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

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

Wavelength[a] [nm]		Aperture	Duration [s]						
			10^{-13} – 10^{-11}	10^{-11} – 10^{-9}	10^{-9} – 10^{-7}	10^{-7} – $1.8 \cdot 10^{-5}$	$1.8 \cdot 10^{-5}$ – $5 \cdot 10^{-5}$	$5 \cdot 10^{-5}$ – 10^{-3}	10^{-3} – 10^{1}
UVC	180 – 280	1 mm for t < 0,3 s; 1,5 · $t^{0,375}$ for 0,3 < t < 10 s	$E = 3 \cdot 10^{10}$ [W m^{-2}] See note[c]		$H = 30$ [J m^{-2}]				
UVB	280 – 302								
	303				$H = 40$ [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]			
	304				$H = 60$ [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]			
	305				$H = 100$ [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]			
	306				$H = 160$ [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]			
	307				$H = 250$ [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]			
	308				$H = 400$ [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]			
	309				$H = 630$ [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]			
	310				$H = 10^{3}$ [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]			
	311				$H = 1{,}6 \cdot 10^{3}$ [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]			
	312				$H = 2{,}5 \cdot 10^{3}$ [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]			
	313				$H = 4{,}0 \cdot 10^{3}$ [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]			
	314				$H = 6{,}3 \cdot 10^{3}$ [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]			
UVA	315 – 400				$H = 5{,}6 \cdot 10^{3}\ t^{0,25}$ [J m^{-2}]				
Visible & IRA	400 – 700	7 mm	$H = 1{,}5 \cdot 10^{-4}\ C_E$ [J m^{-2}]	$H = 2{,}7 \cdot 10^{4}\ t^{0,75}\ C_E$ [J m^{-2}]	$H = 5 \cdot 10^{-3}\ C_E$ [J m^{-2}]		$H = 18\ t^{0,75}\ C_E$ [J m^{-2}]		
	700 – 1 050		$H = 1{,}5 \cdot 10^{-4}\ C_A C_E$ [J m^{-2}]	$H = 2{,}7 \cdot 10^{4}\ t^{0,75}\ C_A C_E$ [J m^{-2}]	$H = 5 \cdot 10^{-3}\ C_A C_E$ [J m^{-2}]		$H = 18\ t^{0,75}\ C_A C_E$ [J m^{-2}]		
	1 050 – 1 400		$H = 1{,}5 \cdot 10^{-3}\ C_E C_C$ [J m^{-2}]	$H = 2{,}7 \cdot 10^{5}\ t^{0,75}\ C_C C_E$ [J m^{-2}]	$H = 5 \cdot 10^{-2}\ C_C C_E$ [J m^{-2}]			$H = 90\ t^{0,75}\ C_C C_E$ [J m^{-2}]	
IRB & IRC	1 400 – 1 500	See note[b]	$E = 10^{12}$ [W m^{-2}] See note[c]		$H = 10^{3}$ [J m^{-2}]				$H = 5{,}6 \cdot 10^{3}\ t^{0,25}$ [J m^{-2}]
	1 500 – 1 800		$E = 10^{13}$ [W m^{-2}] See note[c]		$H = 10^{4}$ [J m^{-2}]				
	1 800 – 2 600		$E = 10^{12}$ [W m^{-2}] See note[c]		$H = 10^{3}$ [J m^{-2}]				$H = 5{,}6 \cdot 10^{3}\ t^{0,25}$ [J m^{-2}]
	2 600 – 10^{6}		$E = 10^{11}$ [W m^{-2}] See note[c]		$H = 100$ [J m^{-2}]	$H = 5{,}6 \cdot 10^{3}\ t^{0,25}$ [J m^{-2}]			

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

b When 1 400 ≤ λ < 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} ≤ λ < 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 gives 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: $5{,}6 \cdot 10^{3}\ t^{0,25}$.

Table 2.3

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

[illegible]		[illegible]	Duration [s]		
			$10^1 - 10^2$	$10^2 - 10^4$	[illegible]
[illegible]	[illegible]	[illegible]	$H = 30$ [J m^{-2}]		
[illegible]	[illegible]		$H = 30$ [J m^{-2}]		
[illegible]	[illegible]		$H = 40$ [J m^{-2}]		
	[illegible]		$H = 60$ [J m^{-2}]		
	[illegible]		$H = 100$ [J m^{-2}]		
	[illegible]		$H = 160$ [J m^{-2}]		
	[illegible]		$H = 250$ [J m^{-2}]		
	[illegible]		$H = 400$ [J m^{-2}]		
	[illegible]		$H = 630$ [J m^{-2}]		
	[illegible]		$H = 1{,}0 \cdot 10^3$ [J m^{-2}]		
	[illegible]		$H = 1{,}6 \cdot 10^3$ [J m^{-2}]		
	[illegible]		$H = 2{,}5 \cdot 10^3$ [J m^{-2}]		
	[illegible]		$H = 4{,}0 \cdot 10^3$ [J m^{-2}]		
	[illegible]		$H = 6{,}3 \cdot 10^3$ [J m^{-2}]		
[illegible]	[illegible]		$H = 10^4$ [J m^{-2}]		
[illegible]	[illegible]	[illegible]	[illegible] $= 100\ C_B$ [J m^{-2}] ([illegible] = 11 mrad) [d]	$E = 1\ C_B$ [W m^{-2}]; ($\gamma = 1{,}1\ t^{0{,}5}$ mrad) [d]	[illegible]
	[illegible]		if $\alpha < 1{,}5$ mrad then $E = 10$ [W m^{-2}] if $\alpha > 1{,}5$ mrad and $t \le T_2$ 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}]		
[illegible]	[illegible]	[illegible]	if $\alpha < 1{,}5$ mrad then $E = 10\ C_A\ C_C$ [W m^{-2}] if $\alpha > 1{,}5$ mrad and $t \le T_2$ 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})		
[illegible]	[illegible]	[illegible]	$E = 1\ 000$ [W m^{-2}]		

a [illegible] is covered by two limits, then the more restrictive applies.

b [illegible] or less, the visible dual limits E from 400 nm to 600 nm reduce to the thermal limits for $10\ s \le t < T_1$ and to photochemical limits for longer [illegible] rated radiance $G = 10^6\ C_B$ [J m^{-2} sr^{-1}] for $t > 10$s 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 [illegible] [illegible] nm as defined by the CIE. The column with wavelength band names is only meant to provide better overview for the user. (The nota[illegible]

c [illegible] = 3,5 mm; for wavelength 10^5 - 10^6 nm: aperture Diameter = 11 mm.

d [illegible]eration of γ is defined as follows: If α (angular subtense of a source) > γ (limiting cone angle, indicated in brackets in the corresponding col[illegible] [illegible] view is used, then the hazard would be overestimated).

[illegible] 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	3,5mm	$E = 10^{12}$ [$W m^{-2}$]	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
	$\lambda < 700$	$C_A = 1,0$
C_A	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	$C_B = 10^{0,02(\lambda - 450)}$
	700 — 1 150	$C_C = 1,0$
C_C	1 150 — 1 200	$C_C = 10^{0,018(\lambda - 1150)}$
	1 200 — 1 400	$C_C = 8,0$
	$\lambda < 450$	$T_1 = 10$ s
T_1	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
	$\alpha < \alpha_{min}$	$C_E = 1,0$
C_E	$\alpha_{min} < \alpha < 100$	$C_E = \alpha/\alpha_{min}$
	$\alpha > 100$	$C_E = \alpha^2/(\alpha_{min} \cdot \alpha_{max})$ mrad with $\alpha_{max} = 100$ mrad
	$\alpha < 1,5$	$T_2 = 10$ s
T_2	$1,5 < \alpha < 100$	$T_2 = 10 \cdot [10^{(\alpha - 1,5)/98,5}]$ 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)