SUBSIDIARY LEGISLATION 424.32

WORK PLACE (MINIMUM HEALTH AND SAFETY REQUIREMENTS FOR THE PROTECTION OF WORKERS FROM RISKS RESULTING FROM EXPOSURE TO ARTIFICIAL OPTICAL RADIATION) REGULATIONS

30th April, 2010

LEGAL NOTICE 250 of 2010.

Title, scope and applicability.

1. (1) The title of these regulations is the Work Place (Minimum Health and Safety Requirements for the Protection of Workers from Risks resulting from Exposure to Artificial Optical Radiation) Regulations.

(2) The scope of these regulations is to lay down minimum requirements for the protection of workers from risks to their health and safety arising or likely to arise from exposure to artificial optical radiation during their work. These regulations refer to the risk to the health and safety of workers due to adverse effects caused by exposure to artificial optical radiation to the eyes and to the skin. These regulations shall implement Directive 2006/25/EC of the European Parliament and of the Council.

(3) These regulations shall apply fully to all workers without prejudice to more stringent and,or more specific provisions contained in any other law or regulation on the protection of workers from the risks related to exposure to artificial optical radiation.

Interpretation.

2. In these regulations, unless the context otherwise requires -

"the Act" means the Occupational Health And Safety Authority Act; Cap. 424.

"the Authority" means the Occupational Health and Safety Authority established by article 8 of the Act;

"exposure limit values" means the limits on exposure to optical radiation which are based directly on established health effects and biological considerations. Compliance with these limits will ensure that workers exposed to artificial sources of optical radiation are protected against all known adverse health effects;

"irradiance (E) or power density" 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 optical radiation from a laser;

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

"the Minister" means the Minister responsible for occupational health and safety;

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

"optical radiation" means any electromagnetic radiation in the wavelength range between 100 nm and 1 mm. The spectrum of optical radiation is divided into ultraviolet radiation, visible radiation and infrared radiation:

(i) ultraviolet radiation: optical radiation of wavelength range between 100 nm and 400 nm. The ultraviolet region is divided into UVA (315-400 nm), UVB (280-315 nm) and UVC (100-280 nm);

(ii) visible radiation: optical radiation of wavelength range between 380 nm and 780 nm;

(iii) infrared radiation: optical radiation of wavelength range between 780 nm and 1 mm. The infrared region is divided into IRA (780 - 1400 nm), IRB (1400 - 3000 nm) and IRC (3000 nm - 1 mm);

"radiance (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 (H)" means the time integral of the irradiance, expressed in joules per square metre ($J\ m^{-2}$).

Exposure limit values.

3. (1) The occupational exposure limit values for non-coherent radiation, other than that emitted by natural sources of optical radiation, are as set out in Schedule I.

(2) The occupational exposure limit values for laser radiation are as set out in Schedule II.

Determination of exposure and assessment of risks.

4. (1) The employer shall assess and, if necessary, measure and,or calculate the levels of exposure to optical radiation to which workers are likely to be exposed so that the measures needed to restrict exposure to the applicable limits can be identified and put into effect. The methodology applied in assessment, measurement and,or calculations shall follow the standards of the International Electrotechnical Commission (IEC) in respect of laser radiation and the recommendations of the International Commission on Illumination (CIE) and the European Committee for Standardisation (CEN) in respect of non-coherent radiation. In exposure situations which are not covered by these standards and recommendations, and until appropriate EU standards or recommendations become available, assessment, measurement and,or calculations shall be carried out using available national or international science-based guidelines. In both exposure situations, the assessment may take account of data provided by the manufacturers of the equipment when it is covered by relevant Community Directives.

(2) The assessment, measurement and,or calculations referred to in sub-regulation (1) shall be planned and carried out by competent persons at suitable intervals taking particular account of regulation 9 concerning protective and preventive services and measures and regulation 13 concerning consultation and participation of the workers of the General Provisions for Health and Safety at Work Places Regulations. The data obtained from the assessment, including those obtained from the measurement and,or calculation of the level of exposure referred to in sub-regulation (1) shall be preserved in a suitable form so as to permit consultation at a later stage. S.L. 424.18

(3) The employer shall give particular attention, when carrying out the risk assessment, to the following:

(*a*) the level, wavelength range and duration of exposure to artificial sources of optical radiation;

(*b*) the exposure limit values referred to in regulation 3;

(*c*) any effects concerning the health and safety of workers belonging to particularly sensitive risk groups;

(*d*) any possible effects on workers' health and safety resulting from workplace interactions between optical radiation and photosensitising chemical substances;

(*e*) any indirect effects such as temporary blinding, explosion or fire;

(*f*) the existence of replacement equipment designed to reduce the levels of exposure to artificial optical radiation;

(*g*) appropriate information obtained from health surveillance, including published information, as far as possible;

(*h*) multiple sources of exposure to artificial optical radiation;

(*i*) a classification applied to a laser as defined in accordance with the relevant IEC standard and, in relation to any artificial source likely to cause damage similar to that of a laser of class 3B or 4, any similar classification;

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

(4) The employer shall be in possession of an assessment of the risk in accordance with regulation 10 of the General Provisions for Health and Safety at Work Places Regulations, and shall identify those measures which must be taken in accordance with regulations 5 and 6 of these regulations. The risk assessment shall be recorded on a suitable medium, and it may include a justification by the S.L. 424.18

employer that the nature and extent of the risks related to optical radiation make a further detailed risk assessment unnecessary. The risk assessment shall be updated on a regular basis, particularly if there have been significant changes which could render it out-of-date, or if the results of health surveillance show it to be necessary.

(5) A medium is considered to be suitable, as required by the preceding sub-regulation, if it allows records and the information contained therein to be stored in a way which is readily accessible for future reference and which meets the following conditions:

(*a*) it is possible for any corrections or other amendments, and the contents of the records prior to such corrections or amendments, to be easily ascertained; and

(*b*) it is not possible for the records otherwise to be manipulated or altered.

Reduction of risks resulting from exposure to artificial optical radiation.

5. (1) Every employer shall take measures to eliminate or reduce to a minimum the risks arising from exposure to artificial optical radiation, taking account of technical progress and of the availability of measures to control the risk at source.

(2) Where the risk assessment carried out in accordance with regulation 4(1) for workers exposed to artificial sources of optical radiation indicates any possibility that the exposure limit values may be exceeded, the employer shall devise and implement an action plan comprising technical and, or organisational measures designed to prevent the exposure exceeding the limit values, taking into account in particular:

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

(*b*) the choice of equipment emitting less optical radiation taking account of the work to be done;

(*c*) technical measures to reduce the emission of 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 Community Directives.

(3) On the basis of the risk assessment carried out in accordance with regulation 4, workplaces where workers could be exposed to levels of optical radiation from artificial sources exceeding the exposure limit values shall be indicated by appropriate signs in accordance with the Workplace (Provision of

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Health and, or Safety Signs) Regulations. The areas in question shall be identified, and access to them limited where this is technically possible and where there is a risk that the exposure limit values could be exceeded.

(4) Workers shall not be exposed above the exposure limit values. In any event, if, despite the measures taken by the employer to comply with these regulations in respect of artificial sources of optical radiation, the exposure limit values are exceeded, the employer shall take immediate action to reduce exposure below the exposure limit values. The employer shall identify the reasons why the exposure limit values have been exceeded, and shall adapt the protection and prevention measures accordingly in order to prevent them being exceeded again. The employer shall adapt the measures referred to in this regulation to the requirements of workers belonging to particularly sensitive risk groups.

Information and training for workers. S.L. 424.18

6. Without prejudice to the provisions of regulations 12 and 14 of the General Provisions for Health and Safety at Work Places Regulations, the employer shall ensure that workers who are exposed to risks from artificial optical radiation at work and,or their representatives, receive any necessary information and training relating to the outcome of the risk assessment provided for in regulation 4 of these regulations, concerning in particular:

(*a*) measures taken to implement these regulations;

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

(*c*) the results of the assessment, measurement and, or calculations of the levels of exposure to artificial optical radiation carried out in accordance with regulation 4 together with an explanation of their significance and potential risks;

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

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

(*f*) safe working practices to minimise risks from exposure;

(*g*) proper use of appropriate personal protective equipment.

Consultation and participation of workers.

7. Consultation and participation of workers and, or their representatives on the matters covered by these regulations and the schedules, including the assessment, measurement and,or calculations of the levels of exposure to artificial optical radiation experienced at work, shall take place in accordance with the General Provisions for Health and Safety at Work Places Regulations. S.L. 424.18

Health surveillance.

8. (1) With the objectives of the prevention and timely detection of any adverse health effects, as well as the prevention of any long-term health risks and any risk of chronic diseases, resulting from exposure to optical radiation, an employer shall make arrangements for carrying out appropriate health surveillance of workers who are exposed to artificial optical radiation and such health records shall be made available to the Authority.

(2) An employer shall ensure that health surveillance is carried out by a doctor or other person which is deemed by the Health Authorities to be competent to carry out health surveillance in accordance with this regulation.

(3) An employer shall ensure that for each worker who undergoes health surveillance in accordance with sub-regulation (1), individual health records are made and kept up-to-date.

(4) (*a*) Health records shall contain a summary of the results of the health surveillance carried out, and shall be kept in a suitable form so as to permit any consultation in a confidential manner at a later date.

(*b*) Copies of the appropriate records shall be supplied to the Authority on request; individual workers shall, at their request, have access to their own personal health records.

(*c*) The employer shall take appropriate measures to ensure that the doctor or the competent person as is referred to in sub-regulation (2) has access to the results of the risk assessment referred to in regulation 4 where such results may be relevant to the health surveillance.

(5) In any event, where exposure above the limit values is detected, a medical examination shall be made available by the employer to any worker concerned. This medical examination shall also be carried out where, as a result of health surveillance, a worker is found to have an identifiable disease or adverse health effect which is considered by a doctor or competent person to be the result of exposure to artificial optical radiation at work. In both cases, when limit values are exceeded or adverse health effects, including diseases, are identified:

(*a*) the worker shall be informed by the doctor or other suitably competent person of the result which relates to him personally, and shall, in particular, receive information and advice regarding any health surveillance which he should undergo following the end of exposure;

(*b*) the employer shall be informed of any significant findings from the health surveillance, taking into account any medical confidentiality;

(*c*) the employer shall:

(i) review the risk assessment carried out pursuant to regulation 4,

(ii) review the measures provided for to eliminate or reduce risks pursuant to regulation 5,

(iii) take into account the advice of the competent person or the Authority in implementing any measure required to eliminate or reduce risk in accordance with regulation 5, and

(iv) arrange continued health surveillance and provide for a review of the health status of any other worker who has been similarly exposed. In such cases, the doctor or competent person or the Authority may propose that exposed persons undergo an adequate medical examination.

Onus of proof.

9. In any proceedings for an offence under these regulations consisting of failure to comply with a duty or requirement to do something, or to do something so far as is reasonably practicable, it shall be for the accused to prove, as the case may be, that it was not practicable or not reasonably practicable to do more than was in fact done to satisfy the duty or requirement, or there was no better practicable means than was in fact used to satisfy the duty or requirement.

Offences.

10. (1) Any breach by any person of any provision of these regulations shall be deemed an offence.

(2) Any person who knowingly or recklessly interferes with the performance of a duty or obligation by a person under these regulations shall be guilty of an offence.

SCHEDULE 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) $$H_{eff} = \int_{0}^{t} \int_{\lambda = 180\ nm}^{\lambda = 400nm} E_{\lambda}(\lambda,t) \cdot S(\lambda) \cdot d\lambda \cdot dt$$ (H_{eff} is only relevant in the range 180 to 400 nm)

(b) $$H_{UVA} = \int_{0}^{t} \int_{\lambda = 315\ nm}^{\lambda = 400nm} E_{\lambda}(\lambda,T) \cdot d\lambda \cdot dt$$ ($H_{UVA=}$ is only relevant in the range 315 to 400 nm)

(c), (d) $$L_B = \int_{\lambda = 300\ nm}^{\lambda = 700nm} L_{\lambda}(\lambda) \cdot B(\lambda) \cdot d\lambda$$ ($L_{B=}$ is only relevant in the range 300 to 700 nm)

(e), (f) $$E_B = \int_{\lambda = 300\ nm}^{\lambda = 700nm} E_{\lambda}(\lambda) \cdot B(\lambda) \cdot d\lambda$$ ($E_{B=}$ is only relevant in the range 300 to 700 nm)

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

(m), (n) $$E_R = \int_{\lambda = 780\ \mathrm{nm}}^{\lambda = 3000\mathrm{nm}} E_\lambda (\lambda) \cdot d\lambda$$ ($E_{R=}$ is only relevant in the range 780 to 3 000 nm)

(o) $$H_{skin} = \int_{0}^{t} \int_{\lambda = 380\ \mathrm{nm}}^{\lambda = 3000\mathrm{nm}} E_\lambda (\lambda, t) \cdot d\lambda \cdot dt$$ (H_{skin} is only relevant in the range 380 to 3 000 nm)

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

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

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

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

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

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

(m), (n) $$E_{IR} = \sum_{\lambda = 370\ nm}^{\lambda = 3000nm} E_\lambda \cdot \Delta\lambda$$

(o) $$E_{skin} = \sum_{\lambda = 380\ nm}^{\lambda = 3000nm} E_\lambda \cdot \Delta\lambda$$ and $H_{skin} = E_{skin} \cdot \Delta t$

Notes:

Eλ (λ,t), Eλ	*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 Eλ (λ, 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 (λ), expressed in watts per square metre [W m^{-2}];
H	*radiant exposure*: the time integral of the irradiance, expressed in joules per square metre U m^{-2}];
H_{eff}	*effective radiant exposure*: radiant exposure spectrally weighted by S (λ), 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 U m^{-2}];
S (λ)	*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;
$L\lambda$ (λ), 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 (λ)	*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 (λ) expressed in watts per square metre per steradian [W m^{-2} sr^{-1}];
B (λ)	*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 (λ), 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 (λ) 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	Exposure limit value	Units	Comment	Part of the body	Hazard
a.	180-400 (UVA, UVB and UVC)	$H_{eff} = 30$ Daily value 8 hours	[J m^{-2}]		eye cornea conjunctiva lens skin	photokeratitis conjunctivitis cataractogenesis erythema elastosis skin cancer
b.	315-400 (UVA)	$H_{UVA} = 10^4$ Daily value 8 hours	[J m^{-2}]		eye lens	cataractogenesis
c.	300-700 (Blue light) *see note 1*	$L_B = \frac{10^6}{t}$ for $t \leq 10\,000$ s	L_B :[W m^{-2} sr^{-1}] t: [seconds]	for $\alpha \geq 11$ mrad	eye retina	photoretinitis
d.	300-700 (Blue light) *see note 1*	$L_B = 100$ for $t > 10\,000$ s	[W m^{-2} sr^{-1}]			
e.	300-700 (Blue light) *see note 1*	$E_B = \frac{100}{t}$ for $t \leq 10\,000$ s	E_B: [W m^{-2}] t: [seconds]	for $\alpha < 11$ mrad *see note 2*		
f.	300-700 (Blue light) *see note 1*	$E_B = 0{,}01$ $t > 10\,000$ s	[W m^{-2}]			

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 run to 1400 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
$700 < \lambda \leq 1\,050$	-	$10^{0,002\,(700-\lambda)}$
$1050 < \lambda \leq 1150$	-	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

SCHEDULE 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.

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

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

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; $1,5 \cdot t^{0,375}$ for 0,3<t<10 s	$E = 3 \cdot 10^{10} \cdot$ [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}]		$H = 18 \cdot t^{0,75}\ C_A\ C_E$ [J m^{-2}]		
	1 050- 1 400		$H = 1,5 \cdot 10^{-3}\ C_C\ C_E$ [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}]			$H = 90 \cdot t^{0,75}\ C_C\ C_E$ [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}]				$H = 5,6 \cdot 10^{3} \cdot t^{0,25}$ [J m^{-2}]
	2 600 - 10^{6}		$E = 10^{11}$ [W m^{-2}] See note [c]		$H = 100$ [J m^{-2}]	$H = 5,6 \cdot 10^{3} \cdot t^{0,25}$ [J m^{-2}]			

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

b When $1\ 400 \leq \lambda < 10^{5}$ nm : aperture diameter = 1 mm for $t \leq 0,3$ 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	3,5 mm	H = 30 [J m^{-2}]		
UVB	303	3,5 mm	H = 40 [J m^{-2}]		
UVB	304	3,5 mm	H = 60 [J m^{-2}]		
UVB	305	3,5 mm	H = 100 [J m^{-2}]		
UVB	306	3,5 mm	H = 160 [J m^{-2}]		
UVB	307	3,5 mm	H = 250 [J m^{-2}]		
UVB	308	3,5 mm	H = 400 [J m^{-2}]		
UVB	309	3,5 mm	H = 630 [J m^{-2}]		
UVB	310	3,5 mm	H = $1,0 \cdot 10^3$ [J m^{-2}]		
UVB	311	3,5 mm	H = $1,6 \cdot 10^3$ [J m^{-2}]		
UVB	312	3,5 mm	H = $2,5 \cdot 10^3$ [J m^{-2}]		
UVB	313	3,5 mm	H = $4,0 \cdot 10^3$ [J m^{-2}]		
UVB	314	3,5 mm	H = $6,3 \cdot 10^3$ [J m^{-2}]		
UVA	315 - 400	3,5 mm	H = 10^4 [J m^{-2}]		
Visible 400 – 700	400 - 600 Photochemical [b] Retinal damage	7 mm	H = 100 C_B [J m^{-2}] (γ = 11 mrad) [d]	E = 1 C_B [W m^{-2}]; (γ = 1,1 $t^{0,5}$ mrad) [d]	E = 1 C_B [W m^{-2}] (γ = 110 mrad) [d]
Visible 400 – 700	400 - 700 Thermal [b] Retinal damage	7 mm	if α < 1,5 mrad then E = 10 [W m^{-2}] if α > 1,5 mrad and t ≤ T_2 then H = 18 C_E $t^{0,75}$ [J m^{-2}] if α > 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 α < 1,5 mrad then E = 10 C_A C_C [W m^{-2}] if α > 1,5 mrad and t ≤ T_2 then H = 18 C_A C_C C_E $t^{0,75}$ [J m^{-2}] if α > 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	$\lambda < 700$	$C_A = 1{,}0$
	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	$C_B = 10^{\,0{,}02(\lambda - 450)}$

Parameter as listed in ICNIRP	Valid spectral range (nm)	Value
C_C	700 - 1 150	$C_C = 1,0$
	1 150 - 1 200	$C_C = 10^{0,018(\lambda - 1150)}$
	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
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)