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 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:

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 [J 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 [J 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];
Δ λ	*bandwidth,* expressed in nanometres [nm], of the calculation or measurement intervals;
Lλ (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 ≤ 10 000 s	L_B :[W m^{-2} sr^{-1}] t: [seconds]	for α ≥ 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 ≤ 10 000 s	E_B: [W m^{-2}] t: [seconds]	for α < 11 mrad *see note 2*		
f.	300-700 (Blue light) *see note 1*	$E_B = 0{,}01$ t >10 000 s	[W m^{-2}]			
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}]	$C_\alpha = 1{,}7$ for α ≤ 1,7 mrad $C_\alpha = \alpha$ for 1,7 ≤ α ≤ 100 mrad $C_\alpha = 100$ for α > 100 mrad $\lambda_1 = 380$; $\lambda_2 = 1\,400$	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}]			

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.

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 $\alpha \leq 11$ mrad $C_\alpha = \alpha$ for $11 \leq \alpha \leq 100$ mrad C_α = 100 for $\alpha > 100$ 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}]			
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	0,012	228	0,1737	276	0,9434	324	0,00052	372	0,000086
181	0,0126	229	0,1819	277	0,9272	325	0,0005	373	0,000083
182	0,0132	230	0,19	278	0,9112	326	0,000479	374	0,00008
183	0,0138	231	0,1995	279	0,8954	327	0,000459	375	0,000077
184	0,0144	232	0,2089	280	0,88	328	0,00044	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	0,00041	378	0,000069
187	0,0166	235	0,24	283	0,8122	331	0,000396	379	0,000066
188	0,0173	236	0,251	284	0,7908	332	0,000383	380	0,000064
189	0,0181	237	0,2624	285	0,77	333	0,00037	381	0,000062
190	0,019	238	0,2744	286	0,742	334	0,000355	382	0,000059
191	0,0199	239	0,2869	287	0,7151	335	0,00034	383	0,000057
192	0,0208	240	0,3	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	0,64	338	0,000303	386	0,000051
195	0,0239	243	0,3347	291	0,6186	339	0,000291	387	0,000049
196	0,025	244	0,3471	292	0,598	340	0,00028	388	0,000047
197	0,0262	245	0,36	293	0,578	341	0,000271	389	0,000046
198	0,0274	246	0,373	294	0,5587	342	0,000263	390	0,000044
199	0,0287	247	0,3865	295	0,54	343	0,000255	391	0,000042
200	0,03	248	0,4005	296	0,4984	344	0,000248	392	0,000041
201	0,0334	249	0,415	297	0,46	345	0,00024	393	0,000039
202	0,0371	250	0,43	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	0,3	348	0,000215	396	0,000035
205	0,051	253	0,4815	301	0,221	349	0,000207	397	0,000033
206	0,0551	254	0,5	302	0,1629	350	0,0002	398	0,000032
207	0,0595	255	0,52	303	0,12	351	0,000191	399	0,000031
208	0,0643	256	0,5437	304	0,0849	352	0,000183	400	0,00003
209	0,0694	257	0,5685	305	0,06	353	0,000175		
210	0,075	258	0,5945	306	0,0454	354	0,000167		
211	0,0786	259	0,6216	307	0,0344	355	0,00016		
212	0,0824	260	0,65	308	0,026	356	0,000153		
213	0,0864	261	0,6792	309	0,0197	357	0,000147		
214	0,0906	262	0,7098	310	0,015	358	0,000141		
215	0,095	263	0,7417	311	0,0111	359	0,000136		
216	0,0995	264	0,7751	312	0,0081	360	0,00013		
217	0,1043	265	0,81	313	0,006	361	0,000126		
218	0,1093	266	0,8449	314	0,0042	362	0,000122		

219	0,1145	267	0,8812	315	0,003	363	0,000118		
220	0,12	268	0,9192	316	0,0024	364	0,000114		
221	0,1257	269	0,9587	317	0,002	365	0,00011		
222	0,1316	270	1,0	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	0,001	368	0,000099		
225	0,15	273	0,9758	321	0,000819	369	0,000096		
226	0,1583	274	0,9679	322	0,00067	370	0,000093		
227	0,1658	275	0,96	323	0,00054	371	0,00009		

TABLE 1.3

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

λ in nm	**B (λ)**	**R (λ)**
300 ≤ λ < 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