AN UPDATE ON OPTICAL RADIATION SAFETY IN EUROPE

F.P. WIERINGA[1,2] AND A.M.T.I. VERMEULEN[3]

1 Corresponding Author: TNO Quality of Life, P.O. Box 2215, 2301 CE, Leiden, The Netherlands; Email: FP.Wieringa@pg.tno.nl

2 Comité Européen de Normalisation (CEN), Technical Committee 169 "Light and Lighting" / Workgroup 8 "Photobiology"

3 Dutch Ministry of Social Affairs and Employment

ABSTRACT

New European legislation, pertaining to optical radiation safety, will appear in 2005. The new EU-Directive adopts the already existing ICNIRP Guidelines for the ultraviolet, visible and infrared range which are internationally recognized as best practice. The legal implications for employers, utilizing optical radiation sources that present a possible hazard, are: (1) determination of health risk for employees, (2) restriction of exposure, (3) medical support, (4) training and information for employees.

INTRODUCTION

For IUVA Members the UV range is most relevant. Human UV exposure can lead to acute effects (skin: erythema; eyes: photokeratitis, photoconjunctivitis) and long term effects (skin: accelerated skin aging, basal cell carcinoma, squamous cell carcinoma, malignant melanoma; eyes: cataract). For the effective radiant exposure H_{eff} (weighted dose) the daily exposure (8 h) limit value is 30 J m^{-2} with an additional requirement that the unweighted UVA dose H_{UVA} shall not exceed a daily exposure limit value of 10^4 J m^{-2}.

The implementation of the new EU-Directive is facilitated by EN 14255, a four part series of European standards. The first part of this series is EN 14255-1 "Measurement and assessment of personal exposures to incoherent optical radiation – Part 1: Ultraviolet radiation emitted by artificial sources in the workplace", which became effective in March 2005.

EUROPEAN OPTICAL RADIATION SAFETY DIRECTIVE (COMING SOON)

The legislative basis for optical radiation safety is formed by the European Union (EU) regulations for Health and Safety in the workplace (EC 1996). These regulations are intended to harmonize the safety approach for all member states. Following the general Directive EU-89/391 for the protection of workers, employers are already required to identify and reduce possible hazards (in general) for workers. Due to the specific characteristics of various physical agents, there was a need to clarify what could be accepted as safe exposure levels. Therefore, the EU started to work on a Physical Agents Directive in 1993. It was soon realized that it was impractical trying to cover all physical agents in one document, and in 1994 the project was split up into several subjects. In due course, particular legislation was released on noise, vibrations and electromagnetic fields up to 300 GHz. So far, however, optical radiation was not yet covered. Instead, limit values recommended by the International Committee on Non-Ionizing Radiation (ICNIRP) were adopted worldwide by most countries as a trustworthy reference for best practice [INIRC/IRPA 1985, 1991; INIRC/IRPA 1991; ICNIRP 1996, 1997, 2004]. Several other international documents, such as the Radtec Convenant (BG/HSE/ CNAMTS/ISPESL 2001) and the 10th Report on Carcinogens (USDHHS 2002) also indicated a need for optical radiation safety awareness, especially in the UV range.

In July 2004, Ireland presented a proposal for a European Optical Radiation Safety Directive, based on the ICNIRP recommendations as a scientific consensus. The intent of the Directive is to prevent acute and long-term effects for eyes and skin.

The implications for employers, utilizing optical radiation sources that present a possible hazard, are:

- determination of health risk for employees
- restriction of exposure
- medical support
- training and information for employees

This EU Directive covers the whole optical spectrum (ultraviolet, visible and infrared) and is intended to protect workers such as welders, laser operators, steel workers and glass workers but also outdoor workers. Publication is expected in April 2005.

Two Annexes in the Directive summarize the ICNIRP guidelines: Annex 1 for incoherent sources and Annex 2 for lasers.

Most IUVA members use UV lamps rather than lasers, hence mainly Annex 1 will be important. However, for a good understanding of what is meant with this regulation, the underlying ICNIRP publications are very useful reading material.

UNDERLYING ICNIRP GUIDELINES

The scientific rationale for the limit values consists of four consecutive publications of the International Committee on Non-Ionizing Radiation (ICNIRP) in the scientific journal Health Physics (INIRC/IRPA 1985, 1991; ICNIRP 1996, 1997, 2004) which reflect how scientific insights have been refined during the last few decades. In addition to photochemical and photothermal effects within the visible and infrared range, these publications give information about acute effects on skin (erythema), eyes (photokeratitis, photoconjunctivitis) and the long term effects of UV exposure on skin (accelerated skin aging, basal cell carcinoma, squamous cell carcinoma, malignant melanoma; eyes: cataract).

ICNIRP has formulated a so-called weighting function $S(\lambda)$ for the combined ultraviolet hazard for skin and eyes (see table 1). The effective dose H_{eff} is calculated by integrating the spectrally weighted irradiance over time and across the UV-range.

The daily exposure dose (H_{eff}) exposure limit (8 hour) value is 30 J m^{-2} (3.0 mJ cm^{-2}).

[1] $$H_{eff} = \int_{0}^{t} \int_{\lambda=180}^{\lambda=400} E(\lambda,t) \cdot S(\lambda) \cdot d\lambda \cdot dt$$

(H_{eff} is only relevant in the range 180 to 400 nm)

where:

- H_{eff} is the *effective radiant exposure*, i.e., the radiant exposure spectrally weighted by $S(\lambda)$, expressed in joules per square meter [J m^{-2}];
- $E_\lambda(\lambda,t)$ is the *spectral irradiance or spectral power density*, that is, the radiant power incident per unit area on a surface, expressed in watts per square meter per nanometer [W m^{-2} nm^{-1}]; values of $E_\lambda(\lambda,t)$ come from measurements or may be provided by the manufacturer of the equipment;
- $S(\lambda)$ is a *spectral weighting factor* taking into account the wavelength dependence of the health effects of UV radiation on eye and skin [dimensionless].

An additional requirement is that the unweighted UVA-dose H_{UVA} shall not exceed a daily exposure limit value of 10^4 J m^{-2} (10^3 mJ cm^{-2}), where

[2] $$H_{UVA} = \int_{0}^{t} \int_{\lambda=315\,nm}^{\lambda=400\,nm} E_\lambda(\lambda,t) \cdot d\lambda \cdot dt$$

(H_{UVA} is only relevant in the range 315 to 400 nm)

where:

- H_{UVA} is the *radiant exposure*, i.e., the time and wavelength integral or sum of the irradiance within the UVA wavelength range 315 to 400 nm, expressed in joules per square meter [J m^{-2}];
- $E_\lambda(\lambda,t)$ is the spectral irradiance or spectral power density, that is, the radiant power incident per unit area on a surface, expressed in watts per square meter per nanometer [W m^{-2} nm^{-1}]; values of $E_\lambda(\lambda,t)$ come from measurements or may be provided by the manufacturer of the equipment;

In addition to the above mentioned UV-exposure limit values, the ICNIRP Guidelines (and therefore the EU-Directive) also provide limit values for effects caused by visible light and infrared radiation.

Values of $S(\lambda)$ for wavelengths not listed in Table 1 may be interpolated with reasonable accuracy using the following three expressions (eqs. 3) which apply only from 210 – 400 nm (ICNIRP 2004):

[3a] $$S(\lambda) = 0.959^{(270-\lambda)} \quad \text{for } 210 \le \lambda \le 270 \text{ nm}$$

[3b] $$S(\lambda) = 1 - 0.36\left(\frac{\lambda - 270}{20}\right)^{1.64} \quad \text{for } 270 < \lambda \le 300 \text{ nm}$$

[3c] $$S(\lambda) = 0.3 \times 0.736^{(\lambda-300)} + 10^{(2-0.0163\lambda)} \quad \text{for } 300 < \lambda \le 400 \text{ nm}$$

IMPLEMENTATION SUPPORTED BY EN 14255-SERIES

"Measurement and assessment of personal exposures to incoherent optical radiation" is the title of an EN 14255 series of European standards that supports the implementation of the above announced EU Directive. These standards pertain to optical radiation safety in the workplace (indoors as well as outdoors) with regard to incoherent optical radiation.

A legislative basis for EN 14255 already existed within the European Union (EU) regulations for Health and Safety in the workplace (EC 1996) but is specified in more detail by the new EU Directive on optical radiation safety of workers.

EN 14255 does not legally apply to optical radiation exposures in leisure time (either by artificial sources like solaria, IR-saunas or by leisure time in the sun), although it certainly may be useful as a guideline to perform such measurements.

According to the CEN/CENELEC internal regulations, the national standards organizations of the following countries are bound to implement this European standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg,

Table 1. UV exposure limits and general weighting factors

λ^a / nm	EL^d / J m^{-2}	EL^d / mJ cm^{-2}	$S(\lambda)^b$	λ^a / nm	EL^d / J m^{-2}	EL^d / mJ cm^{-2}	$S(\lambda)^b$
180	2,500	250	0.012	310	2,000	200	0.015
190	1,600	160	0.019	313[c]	5,000	500	0.006
200	1,000	100	0.030	315	1.0×10^4	1.0×10^3	0.003
205	590	59	0.051	316	1.3×10^4	1.3×10^3	0.0024
210	400	40	0.075	317	1.5×10^4	1.5×10^3	0.0020
215	320	32	0.095	318	1.9×10^4	1.9×10^3	0.0016
220	250	25	0.120	319	2.5×10^4	2.5×10^3	0.0012
225	200	20	0.150	320	2.9×10^4	2.9×10^3	0.0010
230	160	16	0.190	322	4.5×10^4	4.5×10^3	0.00067
235	130	13	0.240	323	5.6×10^4	5.6×10^3	0.00054
240	100	10	0.300	325	6.0×10^4	6.0×10^3	0.00050
245	83	8.8	0.306	328	6.8×10^4	6.8×10^3	0.00044
250	70	7	0.430	330	7.3×10^4	7.3×10^3	0.00041
254[c]	60	6	0.500	333	8.1×10^4	8.1×10^3	0.00037
255	58	5.8	0.520	335	8.8×10^4	8.8×10^3	0.00034
260	46	4.6	0.650	340	1.1×10^5	1.1×10^4	0.00028
265	37	3.7	0.810	345	$1.3 \text{ X } 10^5$	1.3×10^4	0.00024
270	30	3.0	1.000	350	1.5×10^5	1.5×10^4	0.00020
275	31	3.1	0.960	355	1.9×10^5	1.9×10^4	0.00016
280[c]	34	3.4	0.880	360	2.3×10^5	2.3×10^4	0.00013
285	39	3.9	0.770	365[c]	2.7×10^5	2.7×10^4	0.00011
290	47	4.7	0.640	370	3.2×10^5	3.2×10^4	0.000093
295	56	5.6	0.540	375	3.9×10^5	3.9×10^4	0.000077
297[c]	65	6.5	0.460	380	4.7×10^5	4.7×10^4	0.000064
300	100	10	0.300	385	5.7×10^5	5.7×10^4	0.000053
303[c]	250	25	0.120	390	6.8×10^5	6.8×10^4	0.000044
305	500	50	0.060	395	8.3×10^5	8.3×10^4	0.000036
308	1,200	120	0.026	400	1.0×10^6	1.0×10^5	0.000030

a. Wavelengths chosen are representative; other values should interpolated (see eqs. 3a-c).
b. Relative spectral effectiveness. This is the ICNIRP spectral weighting function for determination of H_{eff} and exposure limits
c. Emission lines of a mercury discharge spectrum (ICNIRP 2004).
d. EL for a monochromatic source, but also limited by a dose-rate of 10 kW m^{-2} (1 W cm^{-2}) for durations greater than 1 s, as well in order to preclude thermal effects.

Malta, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

EN 14255 is intended to support the proper and reproducible application of the limit values set in Annex 1 of the Directive. This is achieved by a systematic description of how to proceed when performing measurements and assessments of personal exposures by sources of incoherent optical radiation.

To cover the broad spectrum of optical radiation safety issues, EN 14255 has been split up into 4 parts.

- EN 14255-1 "Ultraviolet radiation emitted by artificial sources in the workplace" – this first part describes how to perform measurements and assessments of personal exposures to artificial ultraviolet radiation sources within the wavelength band of 180 to 400 nm. Ultraviolet radiation is by far the most dangerous spectral region within the optical radiation range. Therefore the UV range is treated in part one, which became effective in March 2005.
- EN 14255-2 "Visible and infrared radiation emitted by artificial sources in the workplace" – this second part describes procedures for the measurement and assessment of personal exposures to artificial visible and/or infrared radiation sources within the wavelength band of 380 to 3000 nm.[1] The reason to also cover this spectral range is that several biological damage mechanisms can be activated by visible and/or infrared optical radiation (ICNIRP 1997), including:
    - Blue Light Hazard (photochemical damage to the retina)
    - Retinal Thermal Hazard (thermal damage to the retina)
    - Cataract (thermally induced)
    - Thermal injury to the skin

  This part was circulated as a final draft standard for voting in February, 2005.
- EN 14255-3 "UV-radiation – Natural sources" – this third part is planned to describe procedures for the measurement and assessment of personal exposures caused by the sun when at work (thus outdoors). Although the same photobiological damage mechanisms apply, a different approach is needed due to the vast differences between artificial sources and the sun (artificial sources can generally be more easily controlled, predicted, handled and/or shielded). The work on this part is currently in progress.
- EN 14255-4 "Quantities for the measurement of incoherent optical radiation exposures" – the work on this fourth part is already in progress, but until the preceding three parts have been finished it will remain subject to changes.

1 For Blue Light Hazard a different wavelength band applies, namely 300 nm to 700 nm.

It is clear that for IUVA members, Part 1 of the series is most important, although also the Blue-Light Hazard and Retinal Thermal Hazard (both covered by Part 2) can be of importance for broad-band sources, such as medium pressure mercury lamps or Xenon lamps.

For closed reactors (e.g., such as those used in water disinfection), the risks are negligible during normal operation but mainly apply to service and manufacturing situations where shields are (partly) opened.

More "open" applications (e.g., such as fluorescence inspection and welding as well as certain curing and printing processes) can also result in human UV-exposure during normal operation.

EN 14255 does not apply to Annex 2 of the EU Directive, which treats coherent sources (lasers). Laser safety issues concerning the primary laser wavelength(s) are covered by the EN-IEC 60825-series of standards[2] (IEC 2001). However, during high power laser cutting and welding processes (even when using infrared lasers like CO_2 or Nd-YAg) non-coherent secondary radiation can be generated within the UV range. Such secondary radiation may well exceed UV exposure limits, sometimes within seconds (Schulmeister, 2002; Hurup et al. 1995) so that in such cases Part 1 of EN 14255 also applies.

REFERENCES

BG/HSE/CNAMTS/ISPESL 2001. Joint Protocol on improved conditions of use of UV-Technology in the printing industry in Germany, the United Kingdom, France, Italy and other interested member states of the European Union, Version 9/2001, Health and Safety Executive, 3 East Grinstead House, London Road, East Grinstead. West Sussex RH 19 1RR, www.hse.gov.uk.

EC 1996. Non-ionizing radiation. Sources, exposure and health effects. Report No. CE-96-96-934-EN-C, European Commission, Brussels. ISBN: 9282792765.

Hurup, K., Glansholm, A., Hietanen, A. von Nandelstadh, P., Schröder, K. 1995. Secondary Radiation Associated with Laser Material Processing, Proceedings of the 3rd EUREKA Industrial Laser Safety Forum, pp. 317-322.

ICNIRP 1996. Guidelines on UV radiation exposure limits, Health Physics, 71(6): 978. www.icnirp.net/downloads.htm.

ICNIRP 1997. Guidelines on limits of exposure to broad-band incoherent optical radiation (0.38 to 3 ìm), Health Physics, 77(3): 539-554. www.icnirp.net/downloads.htm.

ICNIRP 2004. Guidelines on limits of exposure to ultraviolet radiation of wavelengths between 180 nm and 400 nm (incoherent optical radiation), Health Physics, 87(2): 171-186. www.icnirp.net/downloads.htm.

IEC 2001. Safety of laser products - Part 1: Equipment classification, requirements and users' guide. Report No. IEC 60825-1, Edition 1.2 of August 2001.
IEC Central Office, P.O. Box 131, CH - 1211 GENEVA 20, Switzerland.

INIRC/IRPA 1985. INIRC/IRPA Guidelines on limits of exposure to ultraviolet radiation of wavelength between 180nm and 400nm (incoherent radiation), Health Physics, 49(2): 331-340. www.icnirp.net/downloads.htm.

2 The IEC 60825-series has a part that treats non-coherent optical radiation safety issues: IEC TR 60825-9 which is not a standard but a so-called Technical Report (EC 1996).

INIRC/IRPA 1991. Guidelines on limits of exposure to ultraviolet radiation of wavelength between 180 nm and 400 nm, IRPA guidelines on protection against non-ionizing radiation, Pergamon, Oxford, UK.
Schulmeister, K. 2002. CD-ROM Handbook on Industrial Laser Safety - Section 1: Radiation, Austrian Research Centers, Seibersdorf, Austria. Supported by the Commission of the European Communities under the Leonardo da Vinci Programme and by the Austrian Federal Ministry of Education, Science and Culture. ARC Seibersdorf, Austria.
USDHHS 2002. Report on Carcinogens, U.S. Department of Health and Human Services; Public Health Service National Toxicology Program, Pursuant to Section 301(b) (4) of the Public Health Service Act, as amended by Section 262, PL 95-622
Tenth Edition, December 2002. http://ntp.niehs.nih.gov.