# Occupational Exposure to Optical Radiation in the Context of a Possible EU Proposal for a Directive on Optical Radiation

**J B O'Hagan, C M H Driscoll and A J Pearson**

## ABSTRACT

Occupational exposures to optical radiation are reviewed in the context of a possible EU proposal for a Directive on Optical Radiation. The impact of using available international guidelines for limiting exposure is discussed. Critical groups are identified and observations made on developing technologies.

A significant exposure for many people at work comes from the sun. It is unlikely that engineering controls will be effective in managing exposure to this source. However, many other sources of exposure can be controlled at manufacture, potentially reducing the burden on employers.

There are a number of potential exposure situations, particularly relating to the use of light emitting diodes, where exposure data is not available.

This study was funded by the Health and Safety Executive.



Approval: January 2003
Publication: February 2003
£10.00
ISBN 0 85951 507 9

# EXECUTIVE SUMMARY

This report was commissioned by the Health and Safety Executive to consider the impact of any potential legislation to limit occupational exposure to optical radiation. In 1993 the Commission of European Communities published a proposal for a Council Directive on the minimum health and safety requirements regarding exposure of workers to the risks arising from physical agents. This was amended in 1994 but was not taken forward for optical radiation. This report considers changes to exposure limit values since the previous proposal, options available for exposure limit values, sources of exposure, practical risk assessment issues and emerging technologies.

NRPB produced a report in 1994, which included a review of occupational exposure to optical radiation. The intention of this report is to update some of the information in that report and to identify where technology has progressed: particularly where new sources are used.

Persons at work could be exposed to optical radiation from three main categories of optical radiation sources: the sun, broadband optical sources and lasers. Light emitting diodes have been included within the laser category in line with the approach used in international laser safety standards.

# CONTENTS

# 1 INTRODUCTION

## 1.1 Preamble

The National Radiological Protection Board (NRPB) has a statutory responsibility to provide advice and information on standards of protection for exposure to non-ionising radiation. For optical radiations, NRPB has published a document "Advice on Protection against Ultraviolet Radiation" (NRPB 2002a). This complements a review of the relevant scientific evidence for ultraviolet radiation health effects published by the Board's independent Advisory Group on Non-Ionising Radiation (NRPB 2002b).

This present report was commissioned by the Health and Safety Executive (HSE) as input to a regulatory impact assessment on optical sources of non-ionising radiation with regard to a proposal for a European Directive. A review was originally carried out for the HSE and published in 1994 (Allen *et al.* 1994), which considered proposals from the European Commission for a Physical Agents Directive. Part 1 of the report considered optical radiation. Both exposure standards and optical radiation technology have progressed since 1994 and these developments are taken into account in this report.

HSE requested that a full review, similar to that undertaken in the previous report (NRPB-R265), should not be carried out for this work. However, the opportunity was taken to add further details of optical applications, particularly new technologies, including laser and light emitting diode (LED) applications.

## 1.2 Background

In 1993 the Council of the European Communities (CEC) published a proposal for a Directive on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (CEC 1993). The physical agents covered by the proposal were noise, mechanical vibration, optical radiation and electromagnetic fields and waves. Occupational exposure to optical radiation was reviewed by NRPB in report NRPB-R265 (Allen *et al.* 1994) in order to provide data for comparison with action levels and ceiling levels contained in the proposal. The proposal was later amended (CEU 1994) but the revised document was published after the publication of NRPB-R265. The report covered occupational exposure to ultraviolet radiation (UVR), radiation from laser sources and infrared radiation (IRR).

This review provides an assessment of the impact of using various international guidelines as the basis for limiting exposure, termed exposure limit values in the amended proposal (CEU 1994). Potential sources of occupational exposure are identified.

### 1.3 Optical Radiation Spectrum

The optical radiation spectrum is defined as including electromagnetic radiation in the wavelength range 100 nm to 1 mm. The spectrum is divided into ultraviolet, visible and infrared radiations. Each of these regions is subdivided as presented in Table 1.

**TABLE 1 Optical Radiation Wavelength Regions**

| Region | CIE Divisions (nm) | ICNIRP/IEC/ACGIH Divisions (nm) |
|---|---|---|
| Ultraviolet C (UVC) | 100 – 280 | 180 – 280 |
| Ultraviolet B (UVB) | 280 – 315 | 280 – 315 |
| Ultraviolet A (UVA) | 315 – 400 | 315 – 400 |
| Visible | 380 – 760 | 400 – 700 |
| Infrared A (IRA) | 760 – 1 400 | 700 – 1 400 |
| Infrared B (IRB) | 1 400 – 3 000 | 1 400 – 3 000 |
| Infrared C (IRC) | 3 000 – 1 000 000 | 3 000 – 1 000 000 |

The critical tissue at risk following exposure to optical radiation is wavelength dependent. However, it can generally be assumed that it will either be the skin or the eye: tissues at depth are unlikely to be at risk.

## 2 EXPOSURE GUIDELINES

The 1994 proposal for a Physical Agents Directive referred to the 1992-1993 threshold level values published by the American Conference of Governmental Industrial Hygienists (ACGIH). There are currently a number of exposure guidelines that could be incorporated into a future draft Directive and consideration was given to the impact of choosing specific guidelines. The ACGIH threshold limit values are updated each year and the version considered here was the 2001 edition (ACGIH 2001).

The International Commission on Non-Ionizing Radiation Protection (ICNIRP 1999) have published guidelines on limits of exposure for broadband optical radiation in the wavelength range 180 nm to 3 μm and for laser radiation from 180 nm to 1 mm. The laser radiation exposure limit values have been adopted by product standards bodies such as the International Electrotechnical Commission (IEC 2001) as the basis for laser classification and maximum permissible exposure levels.

Since 1993 the International Electrotechnical Commission (IEC) has included light emitting diodes within the scope of the laser safety standard (IEC 2001). It is therefore possible that such products will require classification in a similar manner to laser products.

All of the exposure limit values are based on the same basic data and therefore can be expected to be similar. However, due to the timescale for the production and publication of the various documents there can be differences in detail.

# 3 SOLAR EXPOSURE

## 3.1 Introduction

The sun is the main source of exposure to optical radiation for most people. Ultraviolet radiation (UVR) from the sun at the Earth's surface is associated with a range of adverse health effects, including erythema (skin reddening), skin cancers and eye disorders (NRPB 2002b). The levels of UVR reaching the Earth's surface depend on the time of year, the transmission properties in the atmosphere and the power output of the sun. These levels are expressed in terms of effective UVR irradiance. A summary of the calculated clear sky noontime (peak) erythemally effective UVR irradiances at sea level as a function of latitude (in steps of 5$^{o}$) in the northern hemisphere using typical ozone values is given in Table 2.

**TABLE 2 Calculated clear sky noontime erythemally effective UVR irradiances (mW m$^{-2}$ eff (CIE 1987)) on a horizontal surface as a function of latitude ($^{o}$) and time of year at sea level in the Northern Hemisphere, using typical ozone values (WHO 1994)**

| lat | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 229 | 251 | 260 | 229 | 210 | 207 | 214 | 233 | 278 | 248 | 226 | 221 |
| 5 | 212 | 232 | 242 | 235 | 214 | 213 | 220 | 241 | 258 | 227 | 207 | 206 |
| 10 | 203 | 220 | 229 | 248 | 226 | 225 | 232 | 255 | 244 | 215 | 198 | 175 |
| 15 | 155 | 199 | 201 | 227 | 221 | 226 | 234 | 240 | 223 | 198 | 155 | 135 |
| 20 | 127 | 183 | 191 | 215 | 234 | 239 | 247 | 227 | 212 | 184 | 127 | 111 |
| 25 | 95 | 134 | 165 | 185 | 203 | 227 | 219 | 200 | 194 | 143 | 101 | 84 |
| 30 | 79 | 110 | 157 | 176 | 192 | 215 | 208 | 190 | 186 | 117 | 85 | 56 |
| 35 | 42 | 80 | 114 | 146 | 160 | 188 | 182 | 166 | 148 | 93 | 50 | 31 |
| 40 | 28 | 61 | 93 | 139 | 152 | 178 | 172 | 158 | 121 | 73 | 33 | 21 |
| 45 | 16 | 33 | 66 | 105 | 126 | 158 | 153 | 128 | 93 | 42 | 21 | 13 |
| 50 | 12 | 22 | 54 | 85 | 119 | 150 | 145 | 104 | 77 | 28 | 15 | 8 |
| 55 | 6 | 14 | 33 | 65 | 92 | 130 | 114 | 81 | 48 | 18 | 8 | 4 |
| 60 | 4 | 10 | 21 | 53 | 75 | 105 | 93 | 67 | 31 | 12 | 5 | 2 |
| 65 | 0 | 6 | 14 | 35 | 59 | 85 | 76 | 42 | 21 | 7 | 2 | 0 |
| 70 | 0 | 3 | 10 | 23 | 48 | 70 | 62 | 29 | 15 | 4 | 0 | 0 |
| 75 | 0 | 0 | 6 | 15 | 30 | 53 | 39 | 20 | 9 | 0 | 0 | 0 |
| 80 | 0 | 0 | 3 | 11 | 20 | 33 | 26 | 14 | 5 | 0 | 0 | 0 |
| 85 | 0 | 0 | 2 | 7 | 14 | 23 | 18 | 9 | 2 | 0 | 0 | 0 |
| 90 | 0 | 0 | 0 | 4 | 10 | 16 | 13 | 5 | 0 | 0 | 0 | 0 |

## 3.2 Comparison with exposure limits

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) publishes guidelines for UVR exposure (ICNIRP 1999). The exposure limits given in these guidelines are based solely on scientific data and compliance with these guidelines should provide a healthy working or living environment from exposure to UVR under all normal conditions. The exposure limits for exposure of the eye or the skin may be used to evaluate potentially hazardous exposure from UVR from the sun. The ICNIRP UVR exposure limit for skin and eye is 30 J $m^{-2}$ effective within an 8 hour period. Weighting a clear sky summer solar spectrum at 52°N with the ICNIRP weighting function gives an ICNIRP weighted solar irradiance of 39.5 mW $m^{-2}$ eff. Therefore, under the conditions of the analysis, the conversion factor from erythemal weighting to ICNIRP weighting is 0.24.

**TABLE 3 Approximate time (minutes) to exceed the ICNIRP UVR exposure limit for exposures less than 8h for skin and eye (ICNIRP 1999) as a function of latitude and time of year, assuming a conversion factor based on weighting a clear sky summer solar spectrum at 52°N and the effective irradiance data in Table 1.**

| Lat | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0** | 9 | 8 | 8 | 9 | 10 | 10 | 10 | 9 | 7 | 8 | 9 | 9 |
| **5** | 10 | 9 | 9 | 9 | 10 | 10 | 9 | 9 | 8 | 9 | 10 | 10 |
| **10** | 10 | 9 | 9 | 8 | 9 | 9 | 9 | 8 | 9 | 10 | 11 | 12 |
| **15** | 13 | 10 | 10 | 9 | 9 | 9 | 9 | 9 | 9 | 11 | 13 | 15 |
| **20** | 16 | 11 | 11 | 10 | 9 | 9 | 8 | 9 | 10 | 11 | 16 | 19 |
| **25** | 22 | 16 | 13 | 11 | 10 | 9 | 9 | 10 | 11 | 15 | 21 | 25 |
| **30** | 26 | 19 | 13 | 12 | 11 | 10 | 10 | 11 | 11 | 18 | 25 | 37 |
| **35** | 50 | 26 | 18 | 15 | 13 | 11 | 11 | 13 | 14 | 22 | 42 | 67 |
| **40** | 74 | 34 | 22 | 15 | 14 | 12 | 12 | 13 | 17 | 29 | 63 | 99 |
| **45** | 130 | 63 | 32 | 20 | 17 | 13 | 14 | 16 | 22 | 50 | 99 | 160 |
| **50** | 174 | 95 | 39 | 25 | 18 | 14 | 15 | 20 | 27 | 74 | 139 | 260 |
| **55** | 347 | 149 | 63 | 32 | 23 | 16 | 18 | 26 | 43 | 116 | 260 | >8h |
| **60** | >8h | 209 | 99 | 39 | 28 | 20 | 22 | 31 | 67 | 174 | 417 | >8h |
| **65** | >8h | 347 | 149 | 60 | 35 | 25 | 27 | 50 | 99 | 298 | >8h | >8h |
| **70** | >8h | >8h | 209 | 91 | 43 | 30 | 34 | 72 | 139 | >8h | >8h | >8h |
| **75** | >8h | >8h | 347 | 139 | 69 | 39 | 53 | 104 | 231 | >8h | >8h | >8h |
| **80** | >8h | >8h | >8h | 189 | 104 | 63 | 80 | 149 | 417 | >8h | >8h | >8h |
| **85** | >8h | >8h | >8h | 298 | 149 | 91 | 116 | 231 | >8h | >8h | >8h | >8h |
| **90** | >8h | >8h | >8h | >8h | 209 | 130 | 160 | 417 | >8h | >8h | >8h | >8h |

Applying this to the erythemally effective irradiances given in Table 2, under the conditions of the analysis, the time to exceed the ICNIRP exposure limits can be assessed, as a function of latitude and time of year, as shown in Table 3. The recommended exposure limits can be exceeded by the theoretical noon UVR values from the overhead sun at 0 to 40° latitude for most months throughout the year within 15 minutes. The recommended exposure limits can be exceeded by the theoretical noon UVR values from the overhead sun at 40 to 70° latitude for summer months within 30 minutes. The exposure times given in Table 3 represent potentially worse case situations, which certainly for latitudes greater than 40°N would be unrealistic, due to local climate. Taking into account the possible time for peak irradiances to occur and the potential for and effects of cloud cover, the exposure times (given in Table 3) for latitudes greater than 40°N should be increased by at least a factor of 2 to 3. This factor would be increased still further if personal doses received at various body sites by an outdoor worker were to be assessed.

There is an additional ICNIRP ultraviolet radiation exposure limit for UVA to the eyes of 10 kJ $m^{-2}$ within an 8 hour period. The theoretical maximum UVA irradiances (W $m^{-2}$) as a function of time of year for latitudes between 35 and 70°N are given in Table 4 and the corresponding times to exceed the ICNIRP exposure limit are given in Table 5.

**TABLE 4 Calculated clear sky noontime UVA irradiances (W $m^{-2}$) (UVA from 315 to 400 nm) on a horizontal surface as a function of latitude (°) and time of year at sea level in the Northern Hemisphere.**

| lat | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **35** | 22 | 30 | 40 | 46 | 48 | 49 | 48 | 46 | 40 | 30 | 22 | 18 |
| **40** | 17 | 26 | 35 | 44 | 47 | 48 | 47 | 44 | 36 | 26 | 17 | 14 |
| **45** | 13 | 20 | 31 | 41 | 45 | 46 | 45 | 41 | 32 | 21 | 13 | 11 |
| **50** | 10 | 16 | 28 | 36 | 44 | 45 | 44 | 36 | 28 | 16 | 11 | 8 |
| **55** | 7 | 13 | 22 | 32 | 39 | 42 | 39 | 32 | 23 | 13 | 7 | 5 |
| **60** | 5 | 9 | 17 | 28 | 35 | 38 | 35 | 29 | 18 | 10 | 5 | 3 |
| **65** | 0 | 6 | 14 | 23 | 31 | 33 | 31 | 24 | 14 | 5 | 2 | 0 |
| **70** | 0 | 4 | 11 | 18 | 27 | 30 | 28 | 19 | 11 | 3 | 0 | 0 |

**TABLE 5 Approximate time (minutes) to exceed the ICNIRP UVA exposure limit for exposures less than 8h for the eyes (ICNIRP 1999) as a function of latitude and time of year, assuming the UVA irradiance data in Table 4.**

| lat | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **35** | 8 | 6 | 4 | 4 | 3 | 3 | 3 | 4 | 4 | 6 | 8 | 9 |
| **40** | 10 | 6 | 5 | 4 | 4 | 3 | 4 | 4 | 5 | 6 | 10 | 12 |
| **45** | 13 | 8 | 5 | 4 | 4 | 4 | 4 | 4 | 5 | 8 | 13 | 15 |
| **50** | 17 | 10 | 6 | 5 | 4 | 4 | 4 | 5 | 6 | 10 | 15 | 21 |
| **55** | 24 | 13 | 8 | 5 | 4 | 4 | 4 | 5 | 8 | 13 | 24 | 33 |
| **60** | 33 | 19 | 10 | 6 | 5 | 4 | 5 | 6 | 9 | 17 | 33 | 55 |
| **65** | >8h | 28 | 12 | 8 | 5 | 5 | 5 | 7 | 12 | 33 | 83 | >8h |
| **70** | >8h | 42 | 15 | 9 | 6 | 6 | 6 | 9 | 15 | 55 | >8h | >8h |

The exposure times given in Table 5 represent potentially worse case situations and would be increased under practical considerations of local climate, the geometry of exposure and occupancy times of an outdoor worker at the peak irradiance levels. In addition, the eye has natural aversion responses to limit exposure. Therefore, it is difficult to meaningfully apply the ICNIRP limits in relation to eye exposure to UVR (and other optical radiation) from the sun.

## 3.3 A precautionary approach

Because of the difficulties in applying exposure limits, particularly in relation to eye exposures, to the sun, a precautionary approach has to be adopted, which will ensure that exposures are kept below thresholds for short-term health effects and limit the risk of long-term damage. The measures in a precautionary approach are:

- Minimising exposure to UVR wherever possible
- Avoiding exposures to UVR which are unnecessary
- Avoiding repetitive exposures

In this context, the provision of advice on limiting exposure to UVR is important in respect of avoiding, reducing or limiting the risks of adverse effects on human health.

Persons working outside should be provided with adequate training to understand the hazards involved with sun exposure and to carry out their work safely (HSE 1998, 2000). Health promotion is important in informing people of risks to health of UVR exposure and advising them about the protective measures they can take. The most effective way to protect the skin from solar UVR is to wear suitable UVR protective clothing (e.g. loose clothing with a close weave). The head and neck can be protected with suitable headwear such as a wide brimmed hat or a legionnaire style hat. Where skin remains uncovered, apply sunblock, or broadband sunscreen, with a protection factor of at least 15. This should be applied generously and reapplied frequently.

UVR can enter the eye from a number of directions. Where other considerations with respect to practical safety in the occupational environment allow, suitable UVR protective eyewear should be used. For example, many sunglasses will reduce the amount of UVR entering the eye directly, but will have little effect in reducing UVR entering the eye obliquely if they do not have side protection. The use of goggles or wrap-around sunglasses which completely shield the eyes with UVR absorbing material, protecting the eyes from both direct and peripheral exposure should be used in these circumstances.

The sun’s UVR levels can be expressed in terms of the Global Solar UV Index, which takes on values in the range 1 to 20; the index is proportional to the UVR intensity. The Global Solar UV Index provides a measure of solar UVR levels relevant to health effects (ICNIRP 1995, WHO 2002). As part of the World Health Organization (WHO) objectives in providing information to the public and workers about the potential detrimental effects on health from sun exposure, the Global Solar UV index provides an important input to this policy. It provides a simple universally applicable indicator as to the levels of solar UVR to which people may be exposed anywhere in the world, as shown in Table 6. Daily maximum summer values of up to 8 may be observed in the UK, while values of greater than 10 will be observed for the Mediterranean and lower latitudes (up to 20 in Australia).

**TABLE 6 The Global Solar UV Index (UVI) (WHO 2002)**

| Index Category | UVI range | Additional Information |
|---|---|---|
| Low | 1 to 2 | No protection required |
| Moderate | 3 to 5 | UVR protection recommended* |
| High | 6 to 7 | UVR protection recommended* |
| Very High | 8 to 10 | Extra protection recommended* |
| Extreme | 11 to 20 | Extra protection recommended* |

*UVR protection consists of individuals seeking shade, and using physical protection and of targeted messages from Agencies. Extra protection consists additionally of strengthening the protection messages.

The Global Solar UV Index should ideally address both skin and eye hazards related to sun exposure. However, because of the geometrical complexity of eye exposure, the current Index is principally a concise indicator of the potential for skin injury, although it does also provide a vehicle to raise public awareness in relation to the adoption of protective measures for all adverse health effects from sun exposure.

Ten points to support educational and awareness programmes for protection from UVR and solar radiation are given in Appendix 1. If the published Solar UV Index exceeds 3, measures suitable to minimising solar UVR exposure should be taken.

## 3.4 Groups at risk

Human skin varies greatly in response to exposure to UVR from the sun. In general, there is a more damaging response in individuals who have very fair genetically non pigmented skin with relatively little ability to synthesise melanin (tan) after sun exposure and these are the people that are inherently at greater risk. However, the pattern and severity of sun exposure are also important risk parameters. There is strong epidemiological evidence that excessive cumulative sun exposure causes cutaneous ageing and raises the risk of squamous cell carcinoma of the skin and lip (NRPB 2002b). There is also good evidence that sun exposure is related to the risk of developing basal cell carcinoma and malignant melanoma. Although the pattern of exposure that represents a hazard in these latter cases is uncertain, intense and intermittent exposure of untanned skin may be important and so, to some extent, may be cumulative exposure. The risk of heat stress is considered in Appendix 2.

With respect to the eye, chronic UVR exposure is a major contributor to corneal and conjunctival disorders (NRPB 2002b). Risk is increased where UVR reflectance from surfaces is high in the work environment and where the level of protection is low. In geographical regions where there is a high UVR reflectance, such as from white coral sands, there is also a high incidence of damage to the cornea and conjunctiva. In geographical regions of high solar exposure and to a lesser extent in regions with lower exposure rates, UVR contributes to the occurrence of cortical cataract. Direct viewing of the sun may cause irreversible visual loss from solar retinal burns in the form of solar or foveomacular retinitis.

As outlined previously, protective behaviour, including avoidance of direct exposure to the sun's rays, the wearing of hats, protective clothing and UVR-absorptive sunglasses, appears to reduce risk. However, in relation to eye exposure, the risk of damage is increased by the use of poorly designed sunglasses, which are not wrap-around and/or which screen out the longer wavelength visible radiation, but transmit UVA and blue light. This promotes pupil dilation and therefore increases the retinal irradiation at potentially harmful wavelengths.

With all these potential caveats regarding inherent sensitivity to sun exposure, the pattern and intensity of exposure and the level and suitability of protection, it is difficult to clearly indicate the occupational risk from sun exposure. However, those occupations which may be perceived to carry a higher risk are those involved with sun sensitive individuals having a long occupancy in the sun, at high intensities with low levels of protection. Some sensitive people may be found in occupations such as beach activities (including lifeguards and beach attendants); building, construction and road workers; roofers and thatchers; open-cast miners and gravel pit workers; riggers; gardeners and horticulturists; farm and forestry workers; fruit, flower and vegetable pickers; certain animal trainers and farriers; fishers and others working at or close to a water surface; waste disposal workers; certain workers in the travel, entertainment and transport industries; outdoor sports people and teachers/trainers; and park attendants and rangers. A summary of total numbers in employment in the UK in a number of these occupations (where data are available) is given in Table 7. Groups involved in indoor occupations, such as office, factory and shop workers, carry the least risk from sun exposure, although their social or recreational risk may be high. In this respect, it is often difficult to differentiate between occupational and recreational/social risk with regard to sun exposure.

**TABLE 7 Employment Statistics in the UK (March-May 2001), as supplied by the Department of Trade & Industry's Labour Force Survey (DTI 2001)**

| Employment category | Total in employment (x$10^3$) |
|---|---|
| Agriculture and fishing | 30 |
| Agriculture machinery drivers | 10 |
| Bricklayers and masons | 107 |
| Construction operatives | 86 |
| Farm workers | 68 |
| Forestry workers | 14 |
| Gardeners and grounds people | 138 |
| Glaziers, window fabric and fitters | 62 |
| Horticulturists | 19 |
| Labourers building/woodworking trades | 173 |
| Quarry workers | 14 |
| Refuse and salvage occupations | 20 |
| Road construction | 25 |
| Road sweepers | 11 |
| Roofers, roof tilers and slaters | 42 |
| Scaffolders, stagers and riggers | 22 |
| Sports and leisure assistants | 47 |
| Steel erectors | 15 |
| Travel and tour guides | 18 |
| Window cleaners | 36 |

# 4 NON-COHERENT ARTIFICIAL OPTICAL SOURCES

## 4.1 Exposure limits

The NRPB report R265 (Allen *et al.* 1994) was written with regard to a system of ceiling levels (CLs) based on the 1992 Threshold Limit Values (TLVs) published by the American Conference of Governmental Industrial Hygienists (ACGIH 1992), and action levels (ALs) set at a value corresponding to 0.5 CL. The amended draft Directive (CEU 1994) replaced the term ceiling level with exposure limit value (ELV) (Table 8). It is not clear whether or not any future Directives issued by the Commission of the European Communities would continue to embody these ELVs or whether some other set of published guidelines would be used to establish ELVs. For simplification, ELVs are used throughout this section, even though CL was used in the original NRPB report.

**TABLE 8 Exposure limit values discussed in NRPB-R265**

| Wavelength (nm) | ELV | Protection |
|---|---|---|
| 180 – 400 (UVR) | 30 J m$^{-2}$ eff (8 h) | Skin (and eye below 315 nm) |
| 315 – 400 (UVA) | $10^4$ J m$^{-2}$ (8h) | Eye |
| 400 – 700 | $10^6$ J m$^{-2}$ sr$^{-1}$ eff (t ≤ $10^4$ s) | Blue-light (retina) |
| 400 – 700 | 100 W m$^{-2}$ sr$^{-1}$ eff (t > $10^4$ s) | Blue-light (retina) |
| 400 – 700 | 100 J m$^{-2}$ eff (t ≤ $10^4$ s) | Blue-light (angular subtense α < 11 mrad) |
| 400 – 700 | $10^{-2}$ W m$^{-2}$ eff (t > $10^4$ s) | Blue-light (angular subtense α < 11 mrad) |
| 400 – 1400 | $10^4/\alpha t^{1/2}$ W m$^{-2}$ sr$^{-1}$ eff | Retinal burn |
| 770 – 1400 (IRA) | 6000/α W m$^{-2}$ sr$^{-1}$ eff | Retinal burn (no strong visual stimulus) |
| > 770 (IRR) | 100 W m$^{-2}$ | Delayed lenticular damage |

Most quantitative exposure limits in use are based on the same data as those of the ACGIH limits, and consequently, any ELVs derived from the exposure limits of other bodies would be very similar to those discussed in R265.

### 4.1.1 ACGIH

The 1992 ACGIH TLVs included a proviso (as do the current ACGIH TLVs (ACGIH 2000)) that UVA irradiance for exposures lasting > $10^3$ seconds should be limited to 10 W m$^{-2}$. This was apparently omitted from the proposed Directive discussed in R265. There have been some changes in the TLVs since 1992; the 2001 TLVs are presented in Table 9.

**Table 9 2001 ACGIH TLVs**

| Wavelength (nm) | TLV | Protection |
|---|---|---|
| 180 – 400 (UVR) | 30 J m$^{-2}$ eff (8 h) | Skin (and eye below 315 nm) |
| 315 – 400 (UVA) | $10^4$ J m$^{-2}$ *(t < 1000 s)* | Eye |
| *315 – 400 (UVA)* | *10 W m$^{-2}$ (t ≥ 1000 s)* | *Eye* |
| 400 – 700 | $10^6$ J m$^{-2}$ sr$^{-1}$ eff (t ≤ $10^4$ s) | Blue-light (retina) |
| 400 – 700 | 100 W m$^{-2}$ sr$^{-1}$ eff (t > $10^4$ s) | Blue-light (retina) |
| 400 – 700 | 100 J m$^{-2}$ eff (t ≤ $10^4$ s) | Blue-light (angular subtense α < 11 mrad) |
| 400 – 700 | $10^{-2}$ W m$^{-2}$ eff (t > $10^4$ s) | Blue-light (angular subtense α < 11 mrad) |
| 400 – 1400 | *$50000/\alpha t^{1/4}$ W m$^{-2}$ sr$^{-1}$ eff* | Retinal burn |
| 770 – 1400 (IRA) | 6000/α W m$^{-2}$ sr$^{-1}$ | Retinal burn (no strong visual stimulus) |
| *770 – 3000 (IRR)* | *18000 $t^{-3/4}$ W m$^{-2}$ (t < 1000 s)* | *Corneal and lenticular damage* |
| 770 – *3000* (IRR) | 100 W m$^{-2}$ (t ≥ 1000 s) | *Corneal* and lenticular damage |

Differences from Table 8 are printed in *italics*

### 4.1.2 ICNIRP

The International Commission on Non-Ionizing Radiation Protection has published (ICNIRP 1999) a series of exposure limits (ELs) which are very similar to the ACGIH TLVs. These ELs (Table 10) are used by NRPB when carrying out optical radiation hazard assessments on sources of non-coherent radiation. The spectral weighting functions used by ACGIH and ICNIRP are identical.

**TABLE 10 Current ICNIRP ELs**

| ID | Wavelength (nm) | EL | Protection |
|---|---|---|---|
| *a* | 180 – 400 (UVR) | 30 J $m^{-2}$ eff (8 h) | Skin (and eye below 315 nm) |
| *b* | 315 – 400 (UVA) | $10^4$ J $m^{-2}$ (8 h) | Eye |
| *c* | *300* – 700 | $10^6$ J $m^{-2}$ $sr^{-1}$ eff ($t \leq 10^4$ s) | Blue-light (retina) |
| *d* | *300* – 700 | 100 W $m^{-2}$ $sr^{-1}$ eff ($t > 10^4$ s) | Blue-light (retina) |
| *e* | *300* – 700 | 100 J $m^{-2}$ eff ($t \leq 10^4$ s) | Blue-light (angular subtense $\alpha$ < 11 mrad) |
| *f* | *300* – 700 | $10^{-2}$ W $m^{-2}$ eff ($t > 10^4$ s) | Blue-light (angular subtense $\alpha$ < 11 mrad) |
| *g* | *380* – 1400 | *50000/$\alpha t^{1/4}$ W $m^{-2}$ $sr^{-1}$ eff* | Retinal burn (visual stimulus & t < 10s) |
| *h* | *780* – 1400 (IRA) | 6000/$\alpha$ W $m^{-2}$ $sr^{-1}$ *($t \geq 10$ s)* | Retinal burn (no strong visual stimulus) |
| *i* | *780 – 3000 (IRR)* | *18000 $t^{-3/4}$ W $m^{-2}$ ($t < 1000$ s)* | *Corneal and lenticular damage* |
| *j* | *780 – 3000* (IRR) | 100 W $m^{-2}$ ($t \geq 1000$ s) | *Corneal* and lenticular damage |
| *k* | *780 – 3000 (IRR)* | *20000 $t^{1/4}$ W $m^{-2}$ ($t < 10$ s)* | *Skin* |

The ID letters are for use in cross referencing with Tables 13 and 14

Differences from Table 8 are printed in *italics*

### 4.1.3 Gezondheidsraad

The Health Council of the Netherlands has published its own set of ELs (Gezondheidsraad 1993), which are summarised in Table 11. This set of ELs uses different weighting functions to the ACGIH/ICNIRP guidelines. The ACGIH/ICNIRP and Gezondheidsraad TLVs and ELs for the visible and near infrared regions have been compared and critiqued by the Defence Evaluation and Research Agency on behalf of the Health and Safety Executive (HSE 1999). The conclusion of this critique was that, for health protection purposes, a mixture of the ICNIRP ELs and the Gezondheidsraad EL for delayed lenticular damage would provide optimal protection. The UVR ELs were not considered in this exercise.

**TABLE 11 Gezondheidsraad ELs**

| Wavelength (nm) | EL | Protection |
|---|---|---|
| *180 – 270* | *30 J m$^{-2}$ (24 h)* | *Eye* |
| *270 – 300* | *30 J m$^{-2}$ eff (24 h)* | *Eye and skin* |
| *300 – 400* | *50 J m$^{-2}$ erythemally eff (24 h)* | *Skin* |
| *400 – 700* | *10$^{6}$ J m$^{-2}$ sr$^{-1}$ eff (24 h)* | *Blue-light (retina)* |
| *400 – 1400* | *0.006 + 20t J m$^{-2}$ eff* | *Retinal burn (point source)* |
| *400 – 1400* | *1000 + 50000t$^{1/3}$ + 10$^{5}$t J m$^{-2}$ sr$^{-1}$ eff* | *Retinal burn (extended source)* |
| *300 – 3000* | *250 W m$^{-2}$ eff* | *Delayed lenticular damage* |
| *250 – 10000* | *100 J m$^{-2}$ eff (t < 1μs)* | *Skin and cornea* |
| *250 – 10000* | *100 + 5500t$^{1/4}$ + 1000t J m$^{-2}$ eff* | *Skin and cornea* |
| *250 – 10000* | *1000t J m$^{-2}$ eff (t > 1s)* | *Skin and cornea* |

Differences from Table 8 are printed in *italics*

## 4.2 Changes in limits

### 4.2.1 Weighting functions

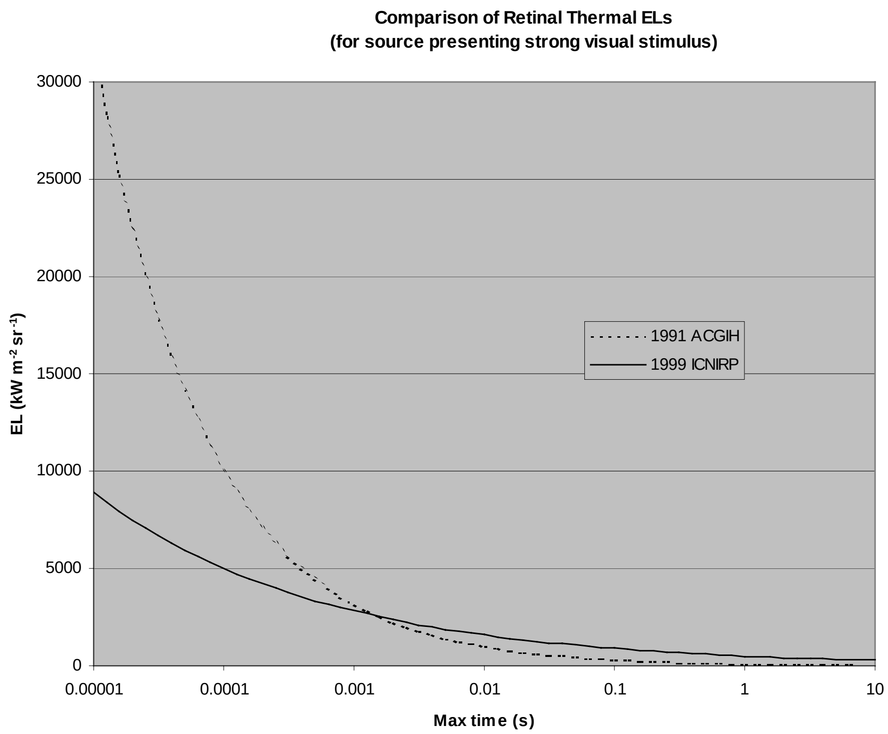
There has been little change in the spectral weighting functions used by ACGIH and ICNIRP since NRPB-R265 was written. There have been some extensions of the wavelength ranges that are included in the TLVs/ELs with, for example, the hazard region for retinal photochemical (blue light) damage being extended from 400 nm down to 300 nm by ICNIRP.

The Gezondheidsraad ELs embody spectral weighting values which differ from the general ACGIH/ICNIRP model. However, the HSE critique of ELs in the visible and near infrared found that the degree of protection offered by both sets of ELs was satisfactory (notwithstanding that some ELs were to be preferred on the basis that they took better account of the current state of knowledge). This being the case, it may be supposed that the changes in UVR/visible/IRA weighting functions that have occurred since NRPB-R265 was published would, if incorporated into a new proposed Directive, not have any very significant effect on the impact of the Directive on industry.

Adoption of the Gezondheidsraad ELs for the skin and cornea would present a major difficulty in application. The use of a spectral weighting function generates a need to acquire spectral data regarding the source of exposure. The highly extended wavelength region of this EL (250 to 10000 nm) greatly complicates the radiometry required to gather data for hazard assessment.

### 4.2.2 Numerical limits

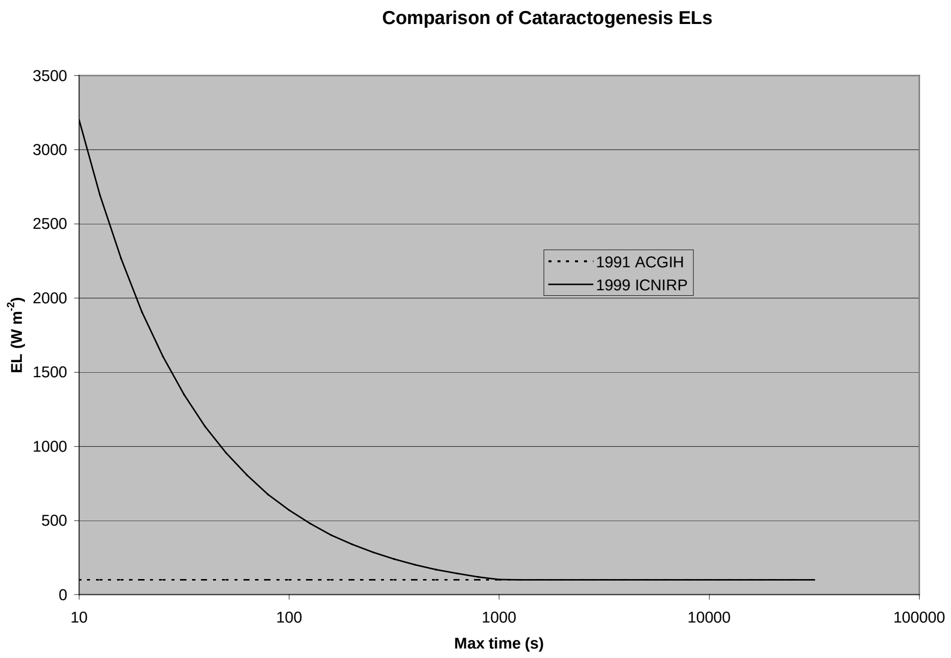
The ACGIH/ICNIRP TLVs/ELs for retinal thermal and delayed lenticular effects are expressed as time dependent formulae. These formulae have been changed since NRPB-R265 was published, and consequently, the numerical values of the TLVs/ELs will differ from those used previously. The former retinal thermal and cataractogenesis ELVs are compared with the current ICNIRP ELs, for a source subtending 0.1 radians, below:




The two sets of limits are equivalent at t = 1.6 ms. For longer exposures, the new ELs are higher, by a factor of up to 8.89 at t = 10 s. For short exposures, the new ELs would be more restrictive, by a factor of up to 3.56 at t = 10 μs.

For cataractogenesis the new exposure limit value is never lower than the old one.

In most cases, these changes represent a relaxation of the ELs (except for retinal exposures of less than 1.6 ms). The new cataractogenesis ELs will permit, in some cases, exposure durations of a few minutes per day where previously sources would have always required countermeasures.




## 4.3 New exposure data

Adoption of ELVs based on the current ACGIH/ICNIRP limits would not significantly alter the conclusions of NRPB-R265 concerning exposure to UVR and retinal photochemical hazards (see R265 part 1 Table 4), as these limits have not changed since R265 was published.

The ELV data for infrared radiation (IRR) exposure in Table 7 of R265 part 1 relate to lenticular and retinal photochemical hazards. The retinal photochemical ELs have not changed. The ELs for lenticular damage are, if anything, more relaxed than formerly.

Hazard assessment software containing data based on measurements extrapolated using a finite-element model has been published by the Institut National de Recherche et de Sécurité (INRS 2000). This enables theoretical hazard assessments to be carried out for a range of optical radiation sources to the ELs of ICNIRP. Data relating to the number of ICNIRP ELs which may be delivered in an 8 hour period, calculated using the INRS database or from NRPB commercial measurements, are presented in Table 12. These data refer to exposure to bare lamps or lamp/reflector assemblies. In normal use, these will generally be incorporated into a housing which will limit unintentional emissions, although service personnel may be at risk of exposure to high levels of optical radiation. The common methods of control for each source are also indicated in Table 12.

**TABLE 12 Summary of number of ICNIRP ELs possible during an 8 hour period for bare sources (ie worst-case scenarios) at 0.5 m (unless otherwise noted). Values less than 1 EL are not shown.**

| Source<br>(*with common methods of controlling exposure*) | Number of ELs per 8 hour day (cross reference letters refer to Table 10) | | | |
|---|---|---|---|---|
| | UVR<br>Skin and eye<br>(EL *a*) | UVA<br>Eye<br>(EL *b*) | Blue light and IRA<br>Retinal<br>(ELs *c to h*) | IRR<br>Corneal / lenticular<br>(ELs *i and j*) |
| 1500 W tungsten halogen<br>*(generally filtered to remove UVR and UVA)* | 237 | 24 | 1.5 | 34 |
| 50 W tungsten halogen<br>*(may be filtered to remove UVR and UVA)* | | | 5.4 | |
| Open arc welding<br>(80 A 22 V 2.5 mm arc)<br>*(use of PPE and shielding, and exclusion of extraneous people)* | 4832 | 29 | 211 | |
| Open arc welding<br>(330 A 37 V 6.3 mm arc)<br>*(use of PPE and shielding, and exclusion of extraneous people)* | 31262 | 223 | 6427 | 4 |
| MIG/MAG welding<br>(low intensity)<br>*(use of PPE and shielding, and exclusion of extraneous people))* | 40226 | 52 | 417 | |
| MIG/MAG welding<br>(high intensity)<br>*(use of PPE and shielding, and exclusion of extraneous people)* | 13152 | 84 | 1251 | 1.7 |
| Flux cored arc welding (low intensity)<br>*(use of PPE and shielding and exclusion of extraneous people)* | 10417 | 65 | 1245 | 1 |
| Flux cored arc welding (high intensity)<br>*(use of PPE and shielding, and exclusion of extraneous people)* | 6007 | 84 | 2405 | 6.8 |
| 125 W blacklight<br>*(often unshielded)* | | 2.9 | 1 | |
| 36 W blacklight<br>*(often unshielded)* | | 5.6 | | |
| 15 W germicidal<br>*(usually embedded in device or shielded)* | 902<br>(3947 at 0.2 m) | | | |
| 1000 W sodium hp<br>*(generally filtered to remove UVR and UVA)* | | 4.9 | | 1.2 |
| 50 W sodium hp<br>*(generally filtered to remove UVR and UVA)* | | | 4.4 | |

**TABLE 12 (continued)**

| Source (*with common methods of controlling exposure*) | Number of ELs per 8 hour day (cross reference letters refer to Table 11) | | | |
|---|---|---|---|---|
| | UVR Skin and eye (EL *a*) | UVA Eye (EL *b*) | Blue light and IRA Retinal (ELs *c to h*) | IRR Corneal / lenticular (ELs *i and j*) |
| 1000 W mercury hp *(generally filtered to remove UVR and UVA)* | 2.5 | 23 | 1212 | |
| 50 W mercury hp *(generally filtered to remove UVR and UVA)* | 1 | 1.6 | 46 | |
| 35 W metal halide *(generally filtered to remove UVR and UVA)* | | | 53 | |
| 400 W metal halide *(generally filtered to remove UVR and UVA)* | 7 | 20 | 766 | |
| Glass polishing torch, 22 mm flame *(PPE for eyes often used)* | 3.5 | | 37 | 9.5 |
| Glass polishing torch, 450 mm flame *(PPE for eyes often used)* | 253 | 2.2 | 35 | |
| Steelworks electric furnace at 1200°C, 0.3 $m^2$ *(Generally low occupancy)* | | | | 3486 |
| Steelworks induction furnace at 1600°C, 0.18 $m^2$ *(Generally low occupancy)* | | | | 307 |
| Ironworks reheating furnace, 1200°C, 2 $m^2$ *(Generally low occupancy)* | 1.9 | | | 2325 |
| Glassworks pot furnace at 1240°C, 0.12 $m^2$ *(Generally low occupancy)* | 1.5 | | | 42 |
| Glassworks pot furnace at 1100°C, 0.04 $m^2$ *(Generally low occupancy)* | | | | 28 |
| Glassworks furnace at 1100°C, 0.05 $m^2$ *(Generally low occupancy)* | | | | 30 |
| Glassworks reheating oven at 1300°C, 0.02 $m^2$ *(Generally low occupancy)* | 3.9 | | | 60 |
| Glassworks reheating oven at 1400°C, 0.04 $m^2$ *(Generally low occupancy)* | 21 | | | 141 |
| Glassworks reheating oven at 1350°C, 0.11 $m^2$ *(Generally low occupancy)* | 141 | | | 411 |
| Glassworks reheating oven at 1350°C, 0.03 $m^2$ *(Generally low occupancy)* | 9.6 | | | 83 |
| Glassworks reheating oven at 1100°C, 0.03 $m^2$ *(Generally low occupancy)* | 1 | | | 20 |
| Glassworks reheating oven at 1500°C, 0.06 $m^2$ *(Generally low occupancy)* | 28 | | | 238 |
| 2.5 kW stage spotlight at 1.7 m *(Usually unshielded)* | 31 | 766 | | |
| Electronic insect trap at 1 m *(usually unshielded but placed out of staff line of sight)* | | 3 | | |

Another way of using these data is to calculate the distances at which the various ICNIRP ELs would be just breached in an 8 hour period. The greatest such distance for any given source gives some idea of the potential extent of the area inside which protective measures may have to be taken. This data is presented in Table 13.

**TABLE 13 Distances at which one ICNIRP EL is delivered during an 8 hour period for bare sources (ie worst-case conditions)**

| Source | Distance from unshielded source (m) | | | |
|---|---|---|---|---|
| | UVR<br>Skin and eye<br>(EL *a*) | UVA<br>Eye<br>(EL *b*) | Blue light and IRA<br>Retinal<br>(ELs *c to h*) | IRR<br>Corneal / lenticular<br>(ELs *i and j*) |
| 1500 W tungsten halogen | 8.2 | 2.6 | 36 | 3.1 |
| 50 W tungsten halogen | 0.3 | | 1.2 | 0.2 |
| Open arc welding (80A 22V 2.5mm arc) | 35 | 2.7 | 7.3 | |
| Open arc welding (330A 37V 6.3 mm arc) | 88 | 7.5 | 40 | 1 |
| MIG/MAG welding (low intensity) | 100+ | 3.6 | 10 | 0.3 |
| MIG/MAG welding (high intensity) | 62 | 4.9 | 18 | 0.7 |
| Flux cored arc welding (low intensity) | 51 | 4.1 | 18 | 0.5 |
| Flux cored arc welding (high intensity) | 39 | 4.6 | 25 | 1.3 |
| 125 W blacklight | 0.2 | 0.9 | 0.5 | |
| 36 W blacklight | 0.1 | 1.5 | | |
| 15 W germicidal | 16 | 0.2 | | |
| 1000 W sodium hp | | 1.2 | | 0.5 |
| 50 W sodium hp | 0.3 | 0.2 | 2.5 | 0.1 |
| 1000 W mercury hp | 0.8 | 2.4 | 17 | 0.3 |
| 50 W mercury hp | 0.5 | 0.6 | 3.4 | |
| 35 W metal halide | 0.4 | 0.4 | 3.6 | |
| 400 W metal halide | 1.3 | 2.3 | 14 | 0.3 |
| Glass polishing torch, 22 mm flame | 0.9 | | 3.1 | 1.6 |
| Glass polishing torch, 450 mm flame | 8.0 | 0.7 | 3.0 | 0.4 |
| Steelworks electric furnace at 1200°C, 0.3 $m^2$ | | | | 36 |
| Steelworks induction furnace at 1600°C 0.18 $m^2$ | 0.3 | | | 9.7 |
| Ironworks reheating furnace, 1200°C, 2 $m^2$ | 4.8 | | | 51 |
| Glassworks pot furnace at 1240°C, 0.12 $m^2$ | 0.6 | | | 3.5 |
| Glassworks pot furnace at 1100°C, 0.04 $m^2$ | 0.2 | | | 2.7 |
| Glassworks furnace at 1100°C, 0.05 $m^2$ | 0.4 | | | 2.8 |
| Glassworks reheating oven at 1300°C, 0.02 $m^2$ | 1.0 | | | 4.0 |
| Glassworks reheating oven at 1400°C, 0.04 $m^2$ | 2.4 | 0.2 | | 6.1 |
| Glassworks reheating oven at 1350°C, 0.11 $m^2$ | 6.3 | 0.3 | | 11 |
| Glassworks reheating oven at 1350°C, 0.03 $m^2$ | 1.6 | | | 4.6 |
| Glassworks reheating oven at 1100°C, 0.03 $m^2$ | 0.5 | | | 2.3 |
| Glassworks reheating oven at 1500°C, 0.06 $m^2$ | 2.8 | 0.3 | | 8.2 |

## 4.4 Industry sectors utilising optical radiation

The number of workers covered by a Directive on optical radiation will depend on the scope of the Directive. If very common uses of optical radiation, such as office lighting, are included, then every business premises in the UK would have to prepare a hazard assessment demonstrating that their application complied with the Directive. The burden imposed by such an undertaking would be more or less onerous according to the availability of useful and objective emission data for common sources. For UK business as a whole, the burden may be similar to that imposed by, for example, the introduction of the Control of Substances Hazardous to Health Regulations.

It is difficult to assess exactly how many businesses in the UK are users of optical radiation for purposes other than lighting. One source is the Department of Trade and Industries' survey of persons in employment sorted by type of occupation (DTI 2001). Approximate data prepared with the aid of this list is presented in Table 14. These data should be interpreted with caution; in some cases – laboratory technicians, for example – a total UK employment figure of 70,000 has been apportioned evenly across the range of sciences.

There are currently approximately 28 million persons employed in the UK. All of these are likely to work in areas that have trivial uses of optical radiation, such as lighting.

The data in Table 14 indicate that (very approximately) 2.4 million employees would be affected to the extent of possibly having to use personal protective equipment or alter their working practices. Given that some of these workers will already be adequately protected (see estimates in Table 14) the extra burden arising from the proposed Directive could affect from 439,000 (existing controls generally not adequate) to 1,309,000 (existing controls generally not adequate plus maybe not adequate) employees and self-employed persons.

However, the main burden of demonstrating compliance will fall on those who have to undertake or supervise hazard assessments, such as managers and safety professionals. Additional control measures such as personal protective equipment could affect up to 1,300,000 additional workers. However, collective protection will require intervention by a much smaller number of persons.

**TABLE 14 Occupational use of optical radiation in the UK**

| Occupational sector *(Existing controls generally adequate?)* | Size of sector: Professionals (000s) | Technical and Skilled trades (000s) | Applications |
|---|---|---|---|
| Science research – chemical *(yes)* | 32 | 28 | UVC fluorescence |
| Science research – Biological *(yes)* | 69 | 28 | UVC fluorescence |
| Engineers – mechanical *(maybe)* | 61 | 14 | UVA fluorescence |
| Engineers – electronic *(yes)* | 31 | 21 | PCB preparation |
| Engineers – QA *(maybe)* | 36 | 14 | UVA fluorescence |
| Medical practitioners *(yes)* | 158 | 468 | Germicidal, phototherapy |
| Opticians *(yes)* | 14 | | Ophthalmoscopy |
| Dentists *(maybe)* | 31 | 17 | Resin curing |
| Police *(maybe)* | | 156 | Fingerprint and stain detection |
| Performing arts *(no)* | | 25 | Spotlights, floodlights, effects lights |
| Entertainment Media *(no)* | | 100 | Spotlights, floodlights, effects lights |
| Horticulture *(maybe)* | | 19 | Horticultural lamps |
| Metal forming and welding *(maybe)* | | 191 | Forges, furnaces, welding |
| Printers *(maybe)* | | 87 | Print curing |
| Food preparation *(yes)* | | 330 | Insect traps |
| Glassware & ceramics *(no)* | | 24 | Furnaces |
| Licensed victualling *(maybe)* | | 196 | Forgery detection |
| Retail *(no)* | | 290 | Forgery detection |
| Furniture *(maybe)* | | 48 | Resin curing |
| **Totals** | **432** | **2056** | |
| ***Of which, existing protection measures probably adequate:*** | | | |
| ***Yes*** | **304** | **875** | |
| ***Maybe*** | **128** | **742** | |
| ***No*** | **0** | **439** | |

## 4.5 Hazard assessment

In practice, the largest impact on a user of optical radiation would be the requirement to undertake a hazard assessment. This is arguably no more onerous than the present requirements under the Management of Health and Safety at Work Regulations for employers to undertake a risk assessment. However, UK regulations embodying a European Directive may spur enforcing bodies to ensure compliance, thus forcing some employers to meet obligations that theoretically already exist.

### 4.5.1 Burdens on non-users of optical radiation

Employers who do not make use of specialised sources of optical radiation will still have optical radiation sources on their premises, e.g. general area and task lighting, photocopiers, etc. A hazard assessment would still be required to identify all sources and verify that they do not pose a hazard, and the judgement that a source does not pose a hazard should be seen to be as objective as possible.

At the time of writing, hazard can only be judged on the basis of either (a) common sense (which is subjective both from the point of view of the person making the judgement and of enforcing bodies deciding to accept it) or (b) radiometry (which would effectively impose on all employers the burdens of being a 'user' of optical radiation, see 4.5.3).

Users of sources which, in themselves, are unlikely to give rise to exposures in excess of the limits would be greatly assisted in hazard assessment if a standardised classification system for optical radiation sources existed. A standard for classification of optical radiation generating machinery is under development by the European Commission for Standardisation (CEN), with part 1 already published as BS EN 12198-1 (BSI 2000). The International Commission on Illumination (CIE) is drafting a standard for lamps and lamp systems. If all lamps, lamp systems and machines that are placed on the market were classified according to these standards, most hazard assessments would be reduced to an exercise in cataloguing sources and their attached classifications.

### 4.5.2 Burdens on manufacturers

The standard for radiation emissions from machinery, BS EN 12198-1, has been published to define how manufacturers can comply with an already existing obligation under the Machinery Directive. The Standard provides a system of classification based on spectroradiometric measurements, which are yet to be fully defined. As the classification system draws heavily on the ICNIRP ELs, the required radiometry is likely to require considerable expertise to be carried out correctly. Any radiometry directed towards a new Directive is unlikely to add to this already existing obligation.

The draft CIE standard could be seen as a burden on lamp manufacturers, if it were to be imposed on them. It would probably require radiometric measurements similar to those that BS EN 12198 will in any case require from machinery manufacturers.

### 4.5.3 Burdens on users

Businesses which utilise optical radiation for specific purposes (such as print curing) should already have hazard assessments for these processes. If such assessments exist, the majority is presumably based on subjective assessments (NRPB has provided radiometry based assessments to approximately 100 customers during the last decade). To date, such hazard assessments have tended to focus on the risk of exceeding the ELs posed by a single piece of equipment. Needless to say, this does not discharge employers' responsibilities to consider all potential sources of exposure in use in the workplace.

The use of optical sources within the media industry, for example within television studios, and the use in entertainment will need special consideration. The conclusions about the hazard may be dependent on the assumptions made about the exposure.

To carry out a full radiometric hazard assessment of the complete range of sources available in any particular workplace would require considerable equipment, expertise and time and therefore would be expensive.

If the burden of radiometric measurement is shifted from users to manufacturers (which is arguably already the case under the Machinery Directive), then hazard assessment for many users will be reduced to a paper exercise. Only those users who find that they have high-risk sources on their premises would need to carry out a more detailed assessment. A more detailed hazard assessment may not necessarily require an expensive radiometric survey – for example, all welding arcs would be high risk under any system of classification, and it is not necessary to carry out radiometry in order to specify adequate protective measures for users of these sources. Where a workplace survey is necessary, access to manufacturer's spectroradiometric classification data would greatly simplify matters.

## 4.6 Summary of Non-Coherent Artificial Sources

The major burden of compliance with a proposed Directive covering non-coherent optical radiation would be that all employers would have to demonstrate compliance. In some cases compliance will only be achieved by the use of countermeasures (estimates of where additional countermeasures are needed for the UK workforce can be found in Table 14). Most indoor worker exposure will be due to sources such as office lighting, and it is difficult, and therefore expensive, for the individual employer to demonstrate objectively that exposure will be below any given EL.

It should be noted that employers are already under an obligation to carry out general risk assessments in the workplace. The burden lies not in the assessment but in gathering objective data towards the assessment, including quantifying the hazard.

The burden on users of optical radiation would be greatly mitigated if manufacturers were obligated to classify emissions from lamps, lamp systems and machinery.

Manufacturers of machinery are already under an obligation under the Machinery Directive. A Directive on optical radiation need not add to this obligation.

Manufacturers of lamps and lamp systems are presently not under any obligation to classify emissions from their products, although in some cases (sunbeds, insect traps) a system of classification does exist.

If lamp manufacturers had the same obligations as machinery manufacturers already have, there would be no need for any appreciable burden to be placed on users of optical radiation unless they employ high-risk sources. Even then, the cost of hazard assessment may be greatly reduced since the manufacturer would already have detailed data on emissions.

# 5 LASER AND LIGHT EMITTING DIODE SOURCES

Sources of laser radiation should be classified by the manufacturer or their agent to give an indication to the user of the laser radiation hazard. Since 1993, the Scope of the International Electrotechnical Commission laser safety standard IEC 60825-1 (IEC 2001) has included light emitting diodes. The British Standard on laser safety, BS EN 60825-1: 1994 (BSI 1994), is technically equivalent to the IEC standard. Laser radiation sources have evolved from research and military applications to become ubiquitous tools across many applications in the workplace and elsewhere. Light emitting diodes are starting to replace incandescent light sources due to their lower electrical power requirements, higher efficiency and longer life.

## 5.1 Exposure Limits

A comparison has been made between the three options considered likely for laser and LED exposure limit values: ICNIRP (ICNIRP 1999), ACGIH (ACGIH 2001) and IEC (IEC 2001). The IEC version of the laser safety standard is used in this report but the British Standard, as amended in September 2002, is identical.

### 5.1.1 Ultraviolet Radiation

The exposure limit values for ultraviolet radiation are presented in Table 15. These are generally identical for ICNIRP, ACGIH and IEC, although the presentation in the three publications is different. There are dual limits for photochemical and thermal effects. The differences between the documents relate to exposure durations less than 1 ns and greater than $10^3$ s. ACGIH provides no guidance below 1 ns, ICNIRP suggests limiting the peak irradiance to the 1 ns exposure limit down to 10 ps and IEC maintains the 1 ns peak irradiance down to 0.1 ps. For exposures greater than $10^3$ s, ICNIRP states $10^4$ J $m^{-2}$, whereas ACGIH and IEC apply the $10^3$ s peak irradiance of 10 W $m^{-2}$.

**TABLE 15 Laser Ultraviolet Radiation Exposure Limit Values**

| Wavelength (nm) | Exposure Duration, t | Exposure Limit Value |
|---|---|---|
| Photochemical | | |
| 180 to 302 | 1 ns to 30 000 s | 30 J $m^{-2}$ |
| 303 | 1 ns to 30 000 s | 40 J $m^{-2}$ |
| 304 | 1 ns to 30 000 s | 60 J $m^{-2}$ |
| 305 | 1 ns to 30 000 s | 100 J $m^{-2}$ |
| 306 | 1 ns to 30 000 s | 160 J $m^{-2}$ |
| 307 | 1 ns to 30 000 s | 250 J $m^{-2}$ |
| 308 | 1 ns to 30 000 s | 400 J $m^{-2}$ |
| 309 | 1 ns to 30 000 s | 630 J $m^{-2}$ |
| 310 | 1 ns to 30 000 s | 1 000 J $m^{-2}$ |
| 311 | 1 ns to 30 000 s | 1 600 J $m^{-2}$ |
| 312 | 1 ns to 30 000 s | 2 500 J $m^{-2}$ |
| 313 | 1 ns to 30 000 s | 4 000 J $m^{-2}$ |
| 314 | 1 ns to 30 000 s | 6 300 J $m^{-2}$ |
| 315 to 400 | 10 s to 1 000 s | 10 000 J $m^{-2}$ |
| 315 to 400 | 1 000 s to 30 000 s | 10 W $m^{-2}$ |
| Thermal | | |
| 180 to 400 | 1 ns to 10 s | $5.6 \times 10^3\ t^{0.25}$ |

### 5.1.2 Retinal Hazard Region

The retinal hazard region is considered to cover the wavelength range 400 to 1400 nm for laser exposure limit values. Whilst the critical exposure is to the retina, the exposure limit values are quoted in terms of the irradiance or radiant exposure at the cornea. The cornea-lens combination may increase the irradiance or radiant exposure at the target tissue by about a factor of $10^5$.

ACGIH, ICNIRP and IEC permit relaxations of the exposure limit value for sources that subtend a large angle. These sources could be arrays of laser diodes or LEDs, or could be large area reflections. The minimum angular subtense for which the relaxation can be applied is 1.5 milliradians in ICNIRP and IEC but a function of exposure duration in ACGIH with breakpoints at 0.7 s and 10 s.

IEC limit the maximum relaxation of the exposure limit value to the ratio of the maximum angular subtense to the minimum angular subtense (100 milliradians/1.5 milliradians = 66.67), whereas ACGIH and ICNIRP express the exposure limit value in terms of a constant radiance for angular subtenses greater than 100 milliradians.

Table 16 contains the exposure limit values from $10^{-13}$ s to 10 s for 400 nm to 1400 nm.

**TABLE 16 Exposure Limit Values for the Retinal Hazard Wavelengths up to 10s**

| Wavelength (nm) | Exposure Duration | Exposure Limit Value (J $m^{-2}$) |
|---|---|---|
| 400 to 700 | 100 fs to 10 ps | $1.4 \times 10^{-4}$ |
| 400 to 700 | 10 ps to 1 ns | $2.7 \times 10^{4}\ t^{0.75}$ |
| 400 to 700 | 1 ns to 18 µs | $5 \times 10^{-3}$ |
| 400 to 700 | 18 µs to 10 s | $18\ t^{0.75}$ |
| 700 to 1050 | 100 fs to 10 ps | $1.5 \times 10^{-4} \times 10^{0.002(\lambda - 700)}$ |
| 700 to 1050 | 10 ps to 1 ns | $2.7 \times 10^{4}\ t^{0.75} \times 10^{0.002(\lambda - 700)}$ |
| 700 to 1050 | 1 ns to 18 µs | $5 \times 10^{-3} \times 10^{0.002(\lambda - 700)}$ |
| 700 to 1050 | 18 µs to 10 s | $18\ t^{0.75} \times 10^{0.002(\lambda - 700)}$ |
| 1050 to 1150 | 100 fs to 10 ps | $1.5 \times 10^{-3}$ |
| 1050 to 1150 | 10 ps to 1 ns | $2.7 \times 10^{5}\ t^{0.75}$ |
| 1050 to 1150 | 1 ns to 50 µs | $5 \times 10^{-2}$ |
| 1050 to 1150 | 50 µs to 10 s | $90\ t^{0.75}$ |
| 1150 to 1200 | 100 fs to 10 ps | $1.5 \times 10^{-3} \times 10^{0.018(\lambda - 1150)}$ |
| 1150 to 1200 | 10 ps to 1 ns | $2.7 \times 10^{5}\ t^{0.75} \times 10^{0.018(\lambda - 1150)}$ |
| 1150 to 1200 | 1 ns to 50 µs | $5 \times 10^{-2} \times 10^{0.018(\lambda - 1150)}$ |
| 1150 to 1200 | 50 µs to 10 s | $90\ t^{0.75} \times 10^{0.018(\lambda - 1150)}$ |
| 1200 to 1400 | 100 fs to 10 ps | $1.2 \times 10^{-2}$ |
| 1200 to 1400 | 10 ps to 1 ns | $2.2 \times 10^{6}\ t^{0.75}$ |
| 1200 to 1400 | 1 ns to 50 µs | 0.4 |
| 1200 to 1400 | 50 µs to 10 s | $720\ t^{0.75}$ |

Note: the relaxation factor for extended-source viewing has not been included.

For exposure durations in excess of 10 s ICNIRP and IEC provide dual limits to take account of thermal and photochemical effects in the visible wavelength range (400 to 700 nm) (Table 17). It is assumed that ACGIH has not yet adopted the modified exposure limit values published by ICNIRP (ICNIRP 1999).

**TABLE 17 ICNIRP and IEC Exposure Limit Values for Long Term Viewing, Retinal Hazard Region**

| Wavelength (nm) | Exposure Duration (s) | Exposure Limit Value |
|---|---|---|
| 400 to 450 (photochemical) | 10 to 100 | 100 J $m^{-2}$ |
| 450 to 600 (photochemical) | 10 to 100 | $100 \times 10^{0.02(\lambda - 450)}$ J $m^{-2}$ |
| 400 to 450 (photochemical) | 100 to 30 000 | 1 W $m^{-2}$ |
| 450 to 600 (photochemical) | 100 to 30 000 | $10^{0.02(\lambda - 450)}$ W $m^{-2}$ |
| 400 to 700 (thermal) | 10 to 30 000 | 10 W $m^{-2}$ |
| 700 to 1050 | 10 to 30 000 | $10 \times 10^{0.002(\lambda - 700)}$ W $m^{-2}$ |
| 1050 to 1150 | 10 to 30 000 | 50 W $m^{-2}$ |
| 1150 to 1200 | 10 to 30 000 | $50 \times 10^{0.018(\lambda - 1150)}$ W $m^{-2}$ |
| 1200 to 1400 | 10 to 30 000 | 400 W $m^{-2}$ |

Note: Extended-source viewing is not considered in this Table. The most restrictive of the photochemical and thermal limits apply from 400 to 600 nm.

The infrared B and C exposure limit values for ICNIRP, IEC and ACGIH are identical except that the 2001 ACGIH publication duplicates the exposure limit values for exposure durations values down to $10^{-14}$ s. Both ICNIRP and IEC retain the 1 ns peak irradiance values down to $10^{-13}$ s. The exposure limit values for the wavelength range 1400 nm to 1 mm and for exposure durations from 1 ns to 30000 s are presented in Table 18.

**TABLE 18 Exposure Limit Values for 1400 nm to 1 mm**

| Wavelength | Exposure Duration (s) | Exposure Limit Value |
|---|---|---|
| 1400 to 1500 nm | $10^{-9}$ to $10^{-3}$ | $10^{3}$ J m$^{-2}$ |
| 1400 to 1500 nm | $10^{-3}$ to 10 | 5600 $t^{0.25}$ J m$^{-2}$ |
| 1500 to 1800 nm | $10^{-9}$ to 10 | $10^{4}$ J m$^{-2}$ |
| 1800 to 2600 nm | $10^{-9}$ to $10^{-3}$ | $10^{3}$ J m$^{-2}$ |
| 1800 to 2600 nm | $10^{-3}$ to 10 | 5600 $t^{0.25}$ J m$^{-2}$ |
| 2600 nm to 1 mm | $10^{-9}$ to $10^{-7}$ | 100 J m$^{-2}$ |
| 2600 nm to 1 mm | $10^{-7}$ to 10 | 5600 $t^{0.25}$ J m$^{-2}$ |
| 1400 nm to 1 mm | 10 to 30 000 | 1000 W m$^{-2}$ |

No account has been taken of the additional complexities in the application of the exposure limit values for extended-source viewing conditions or for multiple pulse exposures.

### 5.1.3 Exposure Limit Values for the Skin

If any proposed Directive places the emphasis on eye protection, the critical organ could shift to be the skin. For large parts of the optical spectrum the exposure limit values for the eye and the skin are identical. Therefore, by inference, any requirement for eye protection would also mean that skin protection should be provided. The exposure limit values are only more restrictive for the eye in the wavelength region 400 to 1400 nm. The exposure limit values for the skin in this wavelength region are presented in Table 19.

**TABLE 19 Laser Exposure Limit Values for the Skin**

| Wavelength (nm) | Exposure Duration (s) | Exposure Limit Value |
|---|---|---|
| 400 to 700 | $10^{-9}$ to $10^{-3}$ | 200 J m$^{-2}$ |
| 400 to 700 | $10^{-3}$ to 10 | 1.1 x $10^{4}$ $t^{0.25}$ J m$^{-2}$ |
| 400 to 700 | 10 to 30 000 | 2000 W m$^{-2}$ |
| 700 to 1050 | $10^{-9}$ to $10^{-3}$ | 200 x $10^{0.002(\lambda - 700)}$ J m$^{-2}$ |
| 700 to 1050 | $10^{-3}$ to 10 | 1.1 x $10^{4}$ x $10^{0.002(\lambda - 700)}$ $t^{0.25}$ J m$^{-2}$ |
| 700 to 1050 | 10 to 30 000 | 2000 x $10^{0.002(\lambda - 700)}$ W m$^{-2}$ |
| 1050 to 1400 | $10^{-9}$ to $10^{-3}$ | 1000 J m$^{-2}$ |
| 1050 to 1400 | $10^{-3}$ to 10 | 5.5 x $10^{4}$ $t^{0.25}$ J m$^{-2}$ |
| 1050 to 1400 | 10 to 30 000 | 10000 W m$^{-2}$ |

### 5.1.4 Implications of Different Exposure Limit Values

The comparison of the exposure limit values from ACGIH, ICNIRP and IEC demonstrate that there will be little practical difference for any proposed

Directive covering optical radiation. IEC 60825-1 (IEC 2001) specifically includes light emitting diodes within its Scope. ACGIH makes no reference to LEDs whereas ICNIRP recognises that the exposure limit values for laser radiation are being adopted by Standards bodies for use with LED sources.

### 5.1.5 Laser Product Classification

IEC 60825-1 includes a laser product classification scheme to assist users of laser products with the control measures required for the safe use of these products. A simplified description of the laser classes is presented in Table 20.

**TABLE 20 Laser Product Classification Scheme – IEC 60825-1 (IEC 2001)**

| Laser Class | Simplified Description |
|---|---|
| 1 | Safe under reasonably foreseeable conditions of operation |
| 1M | As Class 1 but not safe when viewed with optical aids |
| 2 | (Visible laser beams only) The eye is protected by the aversion responses, including the blink reflex and head movement |
| 2M | As Class 2 but not safe when viewed with optical aids |
| 3R | More likely to cause harm to the eye than lower Class lasers but do not need as many control measures as higher Class lasers |
| 3B | Eye damage likely to occur if the beam is viewed directly or from shiny reflections |
| 4 | Eye and skin damage likely from the main laser beam and reflected beams. Class 4 lasers may cause fires |

The laser classification scheme considers the amount of laser radiation a person can get access to under conditions of normal use, taking account of reasonably foreseeable single-fault conditions. Additional consideration is also taken of the likelihood of exposure during maintenance and servicing operations. Each laser class is assigned an accessible emission limit (AEL). A product is assigned to the class where it does not exceed the AEL for that class, but exceeds the AEL of lower classes. Assumptions are also made on the exposure duration as part of the classification process.

LED products should be classified in a similar manner.

The class is a property of the laser (or LED) product and provides an indication of the maximum amount of laser radiation it is possible to get access to. The exposure limit value is relevant for the exposure of people to the laser or LED radiation. The relevant exposure duration for comparison with the exposure limit value may be different to that assumed by the manufacturer who classified the product. It is also important to appreciate that many laser products, particularly class 1, contain embedded laser systems of a higher class.

## 5.2 Exposure to Laser and LED Radiation

A number of occupational sectors have been identified where exposure to laser and/or LED radiation is likely. Where data was available approximate numbers are provided for the number of people who may be at risk. Many laser beams are highly collimated and therefore, unlike broadband optical sources, the exposure of people is generally unlikely. However, if exposure does occur the effect on the recipient can be serious. By definition (under IEC 60825-1), any laser or LED application classified to IEC 60825-1 has the potential for persons to exceed an ELV.

#### 5.2.1 Maintenance and Servicing

Servicing remains a high risk area of work where the main safety control measure is likely to be training and therefore the competence of the person undertaking the work. A number of companies have expressed concerns over the measures taken by service engineers to protect other persons in the environment. It is reasonably foreseeable that persons working in these areas could be exposed to optical radiation levels in excess of the exposure limit value for the eye and the skin. However, the use of personal protective equipment (PPE) may not be the most effective control measure. In particular, an engineer working on some laser equipment may be at greater risk of injury from other hazards and their ability to identify these hazards may be compromised by the PPE.

Maintenance work, which is assumed to be a routine operation carried out by the operator, should not put that individual at greater risk than normally operating the equipment. This is not always the case.

#### 5.2.2 Military Lasers

The use of lasers and LEDs in the military sector continues to increase. It is understood that greater use is being made of free-air optical communication systems rather than radiofrequency systems for battlefield conditions. Laser sources are also used for range-finding, target designation and for combat simulation. By the nature of these applications, engineering control measures may not be practicable.

The nature of many military lasers and LEDs means that geographical areas where the exposure limit value potentially may be exceeded could be quite large. It is understood that the Ministry of Defence applies probabilistic risk assessment (MOD 1998) to many laser applications for training exercises and that this approach is also being considered within NATO. In some applications, the persons at risk may be members of the public.

It is estimated that up to 50,000 service personnel and 50,000 civilian personnel could be at risk of exposure to optical radiation in excess of the exposure limit values at some time during a calendar year.

#### 5.2.3 Medical, Dental, Cosmetic and Veterinary Lasers

The range of lasers and LED devices used for medical, dental and pseudo-medical applications continues to grow. These devices are routinely used for surgery, diagnostic procedures and treatments such as photodynamic therapy. Cosmetic procedures and eye corrective surgery routinely take place in high street clinics.

By the very nature of the treatments being carried out the accessible laser radiation generally exceeds the exposure limit value. The ethos of this industry sector is to rely on personal protective equipment for eye protection and training of the person operating the laser. Engineering control measures could be introduced into this sector but cost and long standing traditions in work practices are hindering development.

It is estimated that 40,000 employees from the NHS, private, veterinary and cosmetic sectors could be exposed to optical radiation in excess of the exposure limit values. The risk of skin exposure may be important in this sector.

### 5.2.4 Construction Lasers

Alignment lasers continue to be used in the construction industry. By the nature of the task they are intended to perform, the laser beams are propagated through the air and therefore potentially accessible. As the cost of the individual lasers has decreased, the number of lasers incorporated into these alignment devices has increased. To increase visibility of the beams to the eye, the tendency has been to incorporate frequency-doubled Nd:YAG lasers into these devices instead of helium-neon or diode lasers emitting red beams. This means that the risk of distraction, dazzle and afterimages has increased for a given radiant power. However, in some cases, the radiant powers have been reduced to produce the same brightness.

The risk of subsequent adverse incidents following sub exposure-limit-value exposures in this industry is significant if other appropriate control measures are not implemented. An example would be accidental exposure of a person working at height without appropriate fall-restraint equipment. The distraction caused by the momentary eye exposure to a laser beam could result in a fall.

At the moment this group is not considered to be at a high risk of direct injury from the products used. However, depending on the criteria used for the exposure limit value, there could be a significant number of employees who may be affected by any potential legislation, probably in excess of 200,000.

### 5.2.5 Manufacturing Lasers (Laser Material Processing)

Lasers are used in a wide range of manufacturing processes. However, the trend has been to move towards class 1 laser products, which present no risk of exposure to the laser beam during normal operation or under reasonably foreseeable single fault conditions. However, as described in 5.2.1 some maintenance and many servicing operations potentially put people at risk of exposure to laser radiation in excess of the exposure limit value.

The number of people working in dedicated laser workshops is probably about 10,000. However, the number of people who are working in industries where lasers are used as part of the manufacturing process, including cutting and welding, is considerably higher – perhaps 100,000.

### 5.2.6 Consumer Lasers

Lasers and LEDs are effectively used for barcode scanning. The applications range from supermarkets, where the public may also operate such equipment, warehouses and baggage handling at airports. Although much of this equipment is class 1 or 2, higher-class laser products are also used. This application probably represents the largest group potentially exposed to laser/LED radiation as part of their routine work. Approximately 1,500,000 people work in these sectors.

CD technology uses laser diodes and lasers or LEDs are contained in "laser" printers. These products are generally class 1 with the laser beams well contained. The use of these products is unlikely to be affected by any proposed Directive.

Infrared LED sources are used to communicate between information technology equipment, for example between a computer and a printer or mobile phone, for hand-held remote control devices and for car security systems. Long term and close proximity exposure is possible and little data appears to be available on the actual exposure levels. Any restriction on exposure in these applications could have an impact on most workers as the technology develops.

#### 5.2.7 Communication Lasers

The use of optical fibre communication technology using laser diodes and LEDs has continued to expand. The pressure to transmit more signals over greater distances without amplification has driven new technology such that laser diode beam powers have increased. There are also laser diodes that can be made to operate over a range of wavelengths.

Where amplification is used, this may be in the form of erbium-doped fibre amplifiers or, more recently, Raman pumped signal regeneration systems. These technologies mean that the power throughout a fibre communication system may not necessarily decrease along the transmission path. In particular, the Raman systems pump about 2 W of optical power into the receive end of the fibre. However, provided the integrity of the fibre communication system is maintained, the risk of exposure to the beam is small. Accidental disconnection of a fibre, or a fibre break, is reasonably foreseeable. The latter may occur in the public domain, for example when digging up the road. These communication systems should have power management systems to counter such exposures but it is understood that these are not always enabled. Additionally, many communication systems transmit a test pulse periodically to determine if a connection has been re-made. Each individual pulse may exceed the exposure limit value.

The number of people working in this industry sector has grown significantly. However, the risk of exposure to the laser/LED radiation is likely to come from failure conditions or during servicing work. Therefore, the maximum number of people potentially exposed to levels in excess of the exposure limit value is unlikely to be greater than 10,000.

Free air optical communication systems are used as primary communication systems, backup to fibre/copper-wire communication systems and for temporary installations. They are currently mainly used between tall buildings but as their operational effectiveness is demonstrated they are likely to receive further use. Most permanent installations are located either on the roof or the wall of the building. However, temporary installations may be floor-mounted internally and directed through windows. Potential exposure situations are during alignment and if someone intercepts the beam (eg a window cleaner).

This industry sector is still relatively new and the number of people currently at risk is probably quite small. However, as the application becomes more widespread the group at risk will encompass those involved in the installation work as well as anyone who could potentially get into the beam path.

Consideration should also be given to evolving technologies where the frequency of communications transmissions exceed the 300 GHz upper limit for radio waves and therefore fall within the scope of optical radiation.

#### 5.2.8 Research Lasers

Lasers are used widely in research environments including University Departments. The laser safety management infrastructure is not always as well developed as in other industries. Lasers continue to be used with beams unnecessarily accessible. Apart from standard laser equipment, developing technologies are used including femtosecond lasers and x-ray lasers.

Commercial equipment using laser technology for research is often of a disappointing standard. Manufacturers produce class 3B and class 4 equipment and expect the user to manage exposure to accessible laser beams. It is rarely necessary for such beams to be accessible. However, it is recognised that much of this equipment is only available from single manufacturers where the user does not have a choice of vendor.

Research applications out of doors may put aircraft pilots and others at risk. This is more likely to be a risk of distraction, dazzle and afterimages from visible laser beams but the risk of exceeding the exposure limit value for all wavelengths needs to be considered.

The primary persons at risk are the researchers who may be students or staff. It is estimated that up to 100,000 persons could be exposed to laser/LED radiation in excess of the exposure limit value.

#### 5.2.9 Display and Entertainment Lasers/LEDs

Lasers continue to be used for light shows, both for the display of laser graphics and beam effects. Although the industry had stagnated during the 1990s, the availability of diode-pumped frequency-doubled Nd:YAG lasers, which are both small and relatively cheap, has generated a bit of a revival. The concern is that the equipment now looks similar to general discotheque lighting and is often used as just another part of the lighting/disc jockey’s repertoire without the more in depth experience of the traditional laser display companies.

Some of these frequency-doubled lasers are not adequately filtered to eliminate one or both of the infrared primary laser beam and the diode pumping beam.

Laser displays taking place out of doors may put aircraft pilots and others at risk of distraction, dazzle and afterimages. Routine scanning of the audience and employees in the audience still takes place at levels in excess of the exposure limit value.

Lighting systems utilising LEDs are starting to be introduced for visual effect.

Visible laser beams continue to be used in tag games alongside infrared laser diodes or LEDs for information transfer. Persons working in these areas could be exposed for extended periods. Similar equipment is also available as toys.

Figures from the industry suggest that approximately 125,000 people work in entertainment environments where exposure to laser or LED radiation in excess of the exposure limit value is possible.

#### 5.2.10 LIDAR

LIDAR technology is used for cloud base measurements and for environmental monitoring. In normal use this technology does not generally present a risk of accidental exposure. However, two occasional exposure scenarios need to be considered: helicopter pilots and passengers who may inadvertently look down the beam; and calibration techniques that require the transceiver unit to be tilted to emit the beam horizontally.

#### 5.2.11 Emergency Services

Police forces throughout the UK utilise laser speed guns. These are understood to be class 1 laser products. Many of the emergency services are starting to use LED-based torches. Exposure to the beam from these devices at close range is likely to exceed the exposure limit value.

#### 5.2.12 General Applications

There are a number of applications for laser/LED technology that may have an impact on a wide range of occupational sectors.

Laser pointers are used as a pointing aid during presentations but also for a wide range of other uses, including during museum/art gallery tours, and a host of other applications where something needs to be pointed out. There have also been a number of incidents where people at work have claimed malicious exposure to radiation from laser pointers.

LEDs are likely to become widely used for area lighting. Depending on the application, persons could work quite close to the source and be exposed throughout each working day to significant levels of optical radiation.

The use of LED technology for the transmission of visual information to the eye is expanding. This includes LED traffic lights, intelligent LED studs to mark roadways and car lighting. Those driving as part of their work will be exposed to these sources but generally the exposure levels will be limited by a need to not dazzle drivers. However, those who may gain closer access to the sources may exceed the exposure limit value. This may include a motor cyclist close behind a car with high-level rear brake light LEDs.

Laser and LED products are being developed for surveillance purposes, both for security applications and, for example, traffic management. A proportion of the persons likely to be exposed will be at work.

There are a small number of products that write information directly on the retina rather than the viewer observing a screen. The radiant power of the lasers used in these devices will be limited by the need to minimise the risk of dazzle. However, if the equipment is to be used for long-term viewing then there is the potential for the exposure limit value to be exceeded.

### 5.3 Summary for Laser and LED Sources

The number of laser and LED applications in the workplace is growing. For a great many applications the optical radiation is, or can be, contained by engineering control measures. The impact of any potential Directive for these applications is negligible. However, maintenance and servicing operations will have to be considered.

There are a limited number of applications where the optical radiation has to be accessible. The hazard will have to be quantified and compared with exposure limit values. However, the assumptions made about the exposure conditions and the parameters used to determine the exposure limit value could be important for determining the risk.

In many research applications the optical radiation could be enclosed but is not. The arguments for not enclosing the beam generally used centre around the need to constantly change the optical arrangement. Unlike many broadband sources, exposure to the radiation from a collimated laser beam only occurs if a worker either gets into the beam path or a reflector is introduced the redirect the beam. Any potential Directive is likely to have the greatest impact in this sector.

## 6 APPLICATION OF THE 1994 DRAFT DIRECTIVE

A review has been carried out of the implications of the individual requirements in the 1994 draft Directive (CEU 1994). Although it is accepted that any future Directive may be written in a different way, it is important to ensure that any specific potential problems are not repeated.

The 1994 amended Draft Proposal has been assessed by requirement in Annex III (Optical Radiation) and comments are made on practical implications of each requirement.

## 6.1 Risk

The wavelength region for optical radiation was defined as 100 nm to 1 mm. All documents referred to thereafter only cover 180 nm to 1 mm. Either the rationale for this should have been given or the wavelength region should have been limited to 180 nm to 1 mm. Whilst exposures below 180 nm are generally not considered a risk from broadband sources, the application of excimer lasers below 180 nm should be considered. Currently there appears to be little data on air attenuation and tissue penetration depths for well collimated and narrow-wavelength-range laser radiation.

Reference is made to exposure to optical radiation during a working day. It is not clear if the exposure limit values that should be applied are those for a working day or for some more reasonable shorter duration. This is also discussed below.

## 6.2 Values

The exposure limit values were taken from ACGIH 1992-1993. It is likely that any future proposal would refer to ICNIRP Guidance. Since the exposure limit values are a function of exposure duration, guidance will need to be given on the duration to be used. A working day of 8 hours may be over cautious for most potential exposure situations. However, using accidental exposure durations, for example 0.25 s for visible radiation and 10 or 100 s for invisible radiation, may be too short.

At many wavelengths the exposure limit values for the eye and the skin will be different. No account was taken of this. When considering "likely" exposure, consideration will have to be taken of the relative probability of exposure of the skin and the eye, and also the difference in exposure limit value. An example would be an area where only hand access was possible.

The treatment of exposures from a number of different sources during a working day will be complex. It is reasonably foreseeable that a person working in an environment with multiple sources, broadband and laser/LED, would have different applicable exposure limit values. These may be additive or independent of each other depending on wavelength.

Threshold values were set at half the exposure limit value. If this requirement is to be retained then it needs to be justified. This was defined as the "exposure value below which continuous and/or repetitive exposure has no adverse effect on health and safety of workers". This implies that the threshold value should be half of the exposure limit value for an 8 hour exposure. If indeed this is the intention then it should be explicitly stated.

A similar argument applies to the setting of an action level at half the exposure limit value. Should this be for an accidental exposure or a full working day?

Table 21 presents a comparison of the exposure limit value for an 8 hour working day with a more realistic accidental exposure duration as a function of wavelength. It can be seen that for wavelengths above 700 nm, the MPE is independent of exposure duration for exposure durations from 100 s to 3 x $10^4$ s. Below 700 nm, the MPEs for 3 x $10^4$ s are more restrictive than for accidental exposure durations.

**TABLE 21 Comparison of Laser/LED Exposure Limit Value for 8 h and a suggested accidental exposure duration**

| Wavelength | 8 hour (3 x $10^4$ s) ELV | Accidental Exposure ELV |
|---|---|---|
| 180 to 302 nm | 1 mW $m^{-2}$ | 300 mW $m^{-2}$ (100 s) |
| 302 to 315 nm | $10^{0.2(\lambda - 295)}/(3 \times 10^4)$ W $m^{-2}$ | $10^{0.2(\lambda - 295)}/100$ W $m^{-2}$ (100 s) |
| 315 to 400 nm | 10 W $m^{-2}$ | 100 W $m^{-2}$ (100s) |
| 400 to 450 nm | 1 W $m^{-2}$ | 25 W $m^{-2}$ (0.25 s) |
| 450 to 500 nm | $10^{0.02(\lambda - 450)}$ W $m^{-2}$ | 25 W $m^{-2}$ (0.25 s) |
| 500 to 700 nm | 10 W $m^{-2}$ | 25 W $m^{-2}$ (0.25 s) |
| 700 to 1050 nm | 10 x $10^{0.002(\lambda - 700)}$ W $m^{-2}$ | 10 x $10^{0.002(\lambda - 700)}$ W $m^{-2}$ (100 s) |
| 1050 to 1150 nm | 50 W $m^{-2}$ | 50 W $m^{-2}$ (100 s) |
| 1150 to 1200 nm | 5 x $10^{0.018(\lambda - 1150)}$ W $m^{-2}$ | 5 x $10^{0.018(\lambda - 1150)}$ W $m^{-2}$ (100 s) |
| 1200 to 1400 nm | 400 W $m^{-2}$ | 400 W $m^{-2}$ (100 s) |
| 1400 nm to 1 mm | 1000 W $m^{-2}$ | 1000 W $m^{-2}$ (100 s) |

The exposure limit values have a “safety factor” built in to them. The requirement to introduce control measures at 50% of this level is difficult to justify. Taking the requirement literally, a person attending a lecture where the presenter is using a 0.6 mW laser pointer would, amongst other requirements, be required to have access to personal protective equipment. It could also be argued that the action level is not restrictive enough. The effect of exposure to visible radiation at levels below the exposure limit value can be significantly dependent on the ambient lighting level. A worker in a darkened room could be visually incapacitated by, for example, a 532 nm laser beam at a radiant power of tens of μW.

## 6.3 Hazardous Activities

This section refers to laser classification. As written, it only applies to class 3B lasers. It is not clear why it did not include class 4. Consideration may also have to be given to class 1M and class 2M products since their safe operation in the workplace is dependent on a risk assessment. Reference should be made to IEC 60825-1: 1994, as amended, or EN 60825-1.

The use of the laser class will need clarification. Specific measurement criteria are given in IEC 60825-1 to determine classification. If this is to be applied to other sources then the relevance of the criteria will need to be assessed.

Article 3 (4), referred to in this section, requires activities to be notified to a responsible authority. This could be difficult to administer depending on how the activity is defined. If the notification is based on the laser (or equivalent) product then this may be manageable. However, if it were to refer to any system, ie a class 1 laser product containing a higher class laser, then it is not clear who would have to notify. There is also the potential for every fibre communication facility to require notification.

There is a requirement for operators to be trained, which is reasonable, but also a requirement for their competence to be checked. It is not clear who would do this – the employer or the responsible authority?

## 6.4 Health Surveillance

NRPB is currently working with the Royal College of Ophthalmologists and HSE on health surveillance and post-incident guidance for laser workers.

A requirement for health surveillance above half the exposure limit value may not be reasonable if the exposure limit value is based on an 8 hour working day. An accidental exposure for 0.25 s to a 0.5 mW 670 nm laser beam will not cause an injury, is unlikely to present a significant dazzle hazard and probably happens frequently. It is also possible that an accidental exposure to a beam from an infrared remote control handset will exceed the exposure limit value for a working day if the device is activated very close to the eye.

This section does not distinguish between man-made and natural sources of optical radiation. The cost of routine medical surveillance for outside workers may need to be considered.

## 6.5 Equipment

The reference to the standard will need to be updated as described above. Since LEDs are included within the scope of the revised standard, there could be a reference to them here. It could also be recognised that a lot of laser equipment is required to comply with the manufacturing requirements of the standard (not just labelling) under the Low Voltage Directive.

## 6.6 Interference

This section on the sub-damage-threshold effects of optical radiation is very important. However, the implications may be wider than the work activity and may effect others carrying out different work activities.

## 6.7 Indirect Effects

The non-beam hazards resulting from the interaction of the optical radiation with material is important. Other optical radiation generated by the interaction should be covered by the requirements of any proposed Directive. Fire and degradation chemical products may be significant and the particular risks from medical laser applications will need to be addressed (eg, release of viable diseased tissue). Where high energy/power laser beams are focussed with sufficient radiant exposure/irradiance to generate a plasma there is also the risk of low energy ionising radiation and this would also need to be addressed.

# 7 CONCLUSIONS

The potential sources of exposure to optical radiation in the workplace have been reviewed along with options for exposure limit values. The choice of exposure limit values does not appear to be critical.

The scope of any proposed Directive would need to be considered. If exposure to natural optical radiation is to be included and the standard exposure limit values applied, for example as published by ICNIRP, then it is likely that there will be a significant burden on employers as well as employees.

It would be reasonable for all man-made optical sources to be subject to assessment. Ideally the manufacturer should carry this out and, based on a classification scheme, the employer would know how much more of an assessment is required in the workplace. The ideal situation would be for equipment to be shielded by effective engineering controls such that routine exposure to optical radiation in the workplace is not possible. If the employer is required to assess every case of optical radiation exposure in the workplace then the burden will be considerable.

It is recognised that there are a number of applications where optical radiation will be accessible in the workplace. The most obvious is area lighting but there are also a number of other applications discussed in the text above. The assessment criteria should be clearly defined to ensure that the risk from the hazard is realistic. The criteria should include guidance on time bases to be used for assessments and measurement locations.

The requirement for persons at work to wear personal protective equipment should be limited to those situations where no other form of protection is practicable. There may be a number of exposure situations where the exposure limit value will be exceeded but no control measure is currently practicable. An example may be the use of lighting in television studios. The implications of this will need to be considered and may require a programme of measurements to determine the magnitude of the exposure.

The introduction of new technology, such as light emitting diodes, is presenting new challenges for hazard quantification and risk assessment. Currently, very few LED products are classified or labelled, despite being a requirement under the laser safety standards in Europe since 1994. However, there are likely to be devices that cannot exceed the exposure limit values under any circumstances. Consideration will need to be given to categories of LED products that it may be possible to exclude from all requirements of any future Directive. The data to support such an exemption may not currently exist.

To summarise, the introduction of a Directive covering optical radiation could present the following problems for employers:

- If the sun is included in the scope then approximately 1,000,000 employees who work out of doors regularly could be subject to assessment and the implementation of control measures.

- The hazard from existing optical radiation sources may not be well quantified and in the absence of a classification scheme for products containing broadband optical radiation sources, employers may have to spend unreasonable time and effort in assessing these hazards. If area lighting is included in the scope of a Directive then this will put a burden on all employers who use artificial lighting. The introduction of a classification scheme for non-laser and non-LED sources is to be encouraged as a means of passing the burden of quantifying optical radiation hazards to manufacturers.

- There are a small number of applications, including theatre and television lighting, where employees are likely to be routinely exposed to optical radiation in excess of the exposure limit value for a part of the working day. Control measures may not be appropriate for these industries.

- A strict application of controls restricting optical radiation in the working environment where the actual risk of exposure to the hazard is small may not be appropriate. For example, a laser beam may only present a risk of injury if access is gained to the actual beam, which may be well defined in space, and not normally accessible.

- The adoption of control measures at exposure levels below the exposure limit values are probably not justified for wavelengths above 700 nm. From 400 to 700 nm there could be a distracting visual stimulus below the exposure limit value, which could have health and safety implications. Consideration should be given to the appropriateness of a precautionary approach to man-made radiation below 400 nm, especially as many sources can be contained by engineering means.

- New sources of optical radiation, including high-brightness LEDs and infrared LEDs used for information transmission applications, need to be considered since they come within the scope of internationally agreed laser safety standards. It may be appropriate to exclude categories of sources from any proposed Directive to minimise the burden on manufacturers and users for measurements.

# 8 REFERENCES


ACGIH (1992). Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. American Conference of Governmental Industrial Hygienists, Cincinnati

ACGIH (2001). 2001 Threshold limit values for chemical substances and physical agents & biological exposure indices. American Conference of Governmental Industrial Hygienists, Cincinnati.

Allen S G, Blackwell R P, Chadwick P J, Driscoll C M H, Pearson A J, Unsworth C and Whillock M J (1994). Review of occupational exposure to optical radiation and electric and magnetic fields with regard to the proposed CEC Physical Agents Directive. Chilton, NRPB-R265.

BSI (1994). Safety of laser products – Part 1: Equipment classification, requirements and user's guide. BS EN 60825-1: 1994, as amended.

BSI (2000). Safety of machinery-assessment and reduction of risks arising from radiation emitted by machinery-part 1: General principles. BS EN 12198-1:2000

CEC (1993). Council of the European Communities. Proposal for a Council Directive on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (93/C 77/02). *Official Journal of the European Communities* **C 77**, 12-29

CEU (1994). Council of the European Union. Amended proposal for a Council Directive on the minimum health and safety requirements regarding the exposure of workers to the risks arising from Physical Agents – Individual Directive in relation to Article 16 of Directive 89/391/EEC (94/C 230/03). *Official Journal of the European Communities* **C 230**, 3-29

CIE (1987). McKinlay, AF and Diffey, BL. A reference UV erythemal action spectrum. CIE J **6**, 17-22.

CIE (1991). Commission Internationale de l'Eclairage (International Commission on Illumination), Sunscreen testing (UVB). Vienna. Technical paper CIE 90

DTI (2001). Employment statistics in the UK (March-May) 2001, as supplied by the DTI Labour Force Survey

FDA (1978). (Department of Health and Human Services of the US Food and Drug Adminstration) Sunscreen drug products for over the counter use; proposed safety, effectiveness and labelling conditions. Federal Register, 43 (166) 38206-69.

Gezondheidsraad (1993). Health Council of the Netherlands. Committee on optical radiation. Optical radiation. Health-based exposure limits for electromagnetic radiation in the wavelength range from 100 nm to 1 mm. The Hague: Health Council of the Netherlands report no. 1993/09E.

HSE (1998). Keep your top on. INDG147(rev).

HSE (1999). A critique of exposure limits for non-ionizing radiation the visible and near-infrared. HSE contract research report 255/1999

HSE (2000). Sun protection – advice for employers of outdoor workers. INDG337.

ICNIRP (1995). Global Solar UV Index. International Commission on Non-Ionizing Radiation Protection. ICNIRP-1/95 .

ICNIRP (1999). Guidelines on Limiting Exposure to Non-Ionizing Radiation, a reference book based on guidelines on limiting exposure to non-ionizing radiation and statements on special applications. R Matthes, J H Bernhardt, A F McKinlay (eds.) International Commission on Non-Ionizing Radiation Protection 1999, ISBN 3-9804789-6-3

IEC (2001). Safety of laser products – Part 1: Equipment classification, requirements and user's guide. IEC 60825-1, Edition 1.2, Geneva.

INRS (2000). CatRayon CD-Rom interactif pour l'évaluation des risques relatifs aux sources de rayonnement optique.

MOD (1998). Military Laser Safety, JSP 390, Ministry of Defence Ordnance Board D/OB/2407/2.

NRPB (2002a). Documents of the NRPB Volume 13, no 3. Advice on Protection Against Ultraviolet Radiation

NRPB (2002b). Documents of the NRPB Volume 13, no 1. Board Statement on Effects of Ultraviolet Radiation on Human Health and Health Effects from Ultraviolet Radiation Sydney (2002). Risk Management Office: The University of Sydney NSW 2006 (http://www.usyd.edu.au).

WHO (1994). United Nations UNEP/WHO/ICNIRP, 1994. Ultraviolet Radiation. Environmental Health Criteria 160. United Nations Environmental Programme, World Health Organization, International Commission on Non-Ionizing Radiation Protection. (Geneva: WHO).

WHO (2002). Global Solar UV Index – a  practical guide. A joint recommendation of World health Organization, World Meteorological Organization, United Nations Environmental Programme, International Commission on Non-Ionizing Radiation Protection. Geneva

# APPENDIX 1 MINIMISING SUN-INDUCED SKIN AND EYE DAMAGE

| Ten ways to minimise sun-induced skin and eye damage applied to occupational exposure (after NRPB 2002b) | |
|---|---|
| 1. | Take sensible precautions to avoid sunburn. |
| 2. | Remember that a suntan offers only modest protection against further exposure. It is not an indication of good health. |
| 3. | Limit unprotected personal exposure to solar radiation, particularly during the four hours around noon, even in the UK and similar latitudes. |
| 4. | Seek shade wherever possible, but remember sunburn can occur even when in partial shade or when cloudy. |
| 5. | Remember that overexposure of skin and eyes can occur while in or at the surface of water and is more likely when there is a high level of reflected UVR, such as from snow and sand. |
| 6. | Wear suitable head wear, such as a wide-brimmed hat, to reduce exposure to the face, head and neck. |
| 7. | Cover skin with clothing giving good protection – examples are long-sleeved shirts and loose clothing with a close weave. |
| 8. | Sunglasses and other eye protection should exclude both direct and peripheral exposure of the eye, i.e. be of a wrap-around design. |
| 9. | Apply sunblocks, or broad-band sunscreens with high sun protection factors (at least SPF* 15) to exposed skin. Apply generously and reapply frequently. |
| 10. | Remember that certain individuals have abnormal skin responses to UVR exposure and may need medical help. Certain prescribed drugs, medicines, foods, cosmetics and plant materials can make people more sensitive to sunlight. |

*The sun protection factor (SPF) is the ratio of the UVR exposure to produce minimal erythema on a skin site protected by sunscreen to the UVR exposure to produce a comparable erythema on unprotected skin (FDA, 1978; CIE, 1991). A SPF of 10 would reduce exposure to 10% of that of unprotected skin.

# APPENDIX 2 HEAT STRESS

The risk of heat stress arises from a combination of human physical effort, which increases body temperature, and the ability of the body to shed the excess heat in order to maintain a viable core body temperature. Heat loss from the body depends on environmental factors such as radiant heat, air temperature, relative humidity and air movement. It also depends on personal factors such as intensity of physical work, acclimatisation, fitness and state of health, and clothing being worn. Even at rest, the body produces some heat. Heat loss can occur through conduction, radiation, convection and evaporation of sweat. This last mechanism is the most important in hot conditions.

Apart from the possibilities of heat stress or heat stroke, which are very rare in industry, working in seasonal heat can effect health and safety in a variety of ways. These include by:

- reducing ability to concentrate
- increasing discomfort when wearing protective clothing and using protective equipment
- aggravating the effects of other hazards such as noise
- aggravating pre-existing illnesses.

Dehydration can occur unless fluid balance is maintained (Sydney, 2002)