Assessment of Personal Exposures to Non-laser Optical Radiation in Entertainment

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ABSTRACT

New legislation has been introduced covering worker exposure to artificial optical radiation. The document explains the impact of the legislation on the entertainment industry and proposes a methodology for assessing the risks. Where practicable, manufacturer's data may be used to assist with the risk assessment. A number of examples of assessments for a range of entertainment applications are included in annexes.

This report was part-funded by the Professional Lighting and Sound Association.

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Approval: February 2011
Publication: March 2011
£21.00
ISBN 978-0-85951-689-1

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1 INTRODUCTION

A wide range of legislation applies to the entertainment industry. In April 2010 the Control of Artificial Optical Radiation at Work Regulations were added to the list. For employers who have already carried out risk assessments under the Management of Health and Safety at Work Regulations (MHSWR), there may be little more to do than to revisit those risk assessments. However, the scope of sources covered by the new Regulations is very wide – essentially all sources except the sun. Therefore, at a minimum, it will be necessary to decide if all relevant sources have been covered.

This document is aimed at venue managers, production companies, lighting designers, safety professionals and others who are involved with the use of lighting in the entertainment industry. The scope also covers sources that emit invisible optical radiation, for example UV cannons.

The information in this document is intended to guide employers to areas where a detailed and complex assessment should not be required, recognising that many sources do not present a risk of injury to employees during the course of their work at the locations where they are likely to be exposed. Other sources may need a more detailed assessment, but information provided by the manufacturer of the lamp or luminaire could provide assistance and reassurance.

The document consists of a short main text followed by a number of supporting annexes. These provide background information and also a number of detailed assessments of a range of entertainment lighting applications.

2 LEGISLATION

Two types of legislation apply to lighting systems used in the entertainment industry: that which applies to the manufacture and supply of the equipment; and that which applies to its use. The former is intended to provide a consistent standard across European Member States and the latter sets the minimum standard.

Manufacture and Supply

Much of the legislation covering the manufacture and supply of lighting systems has been around for a number of years.

Section 6 of the Health and Safety at Work etc Act 1974 (HSWA) requires designers, manufacturers, importers and suppliers of equipment that is used at work to: ensure that the equipment is safe when used, cleaned or maintained; provide adequate information so that the user can assess the risks, including when the equipment is dismantled; and provide follow-up information to avoid serious injury.

This Act is specific to the UK, but a number of Regulations apply to equipment supplied in the UK as a result of European requirements. The Electrical Equipment (Safety) Regulations 1994 covers products that use between 50 and 1,000 volts AC or 75 and 1,500 volts DC. This will cover most lighting systems. The essential requirements are that the product should be safe, and emissions of “radiation”, which includes optical radiation, should be such that they “would not cause a danger”. The Regulations also require equipment to be CE marked.

Use of Equipment

A number of goal-setting Regulations have been made under the Health and Safety at Work etc Act. Many of these generally apply and therefore are relevant to the use of lighting systems in the entertainment industry. These include the Management of Health and Safety at Work Regulations (MHSWR) 1999, which place a general duty on employers to assess the risks from their work activities. The Provision and Use of Work Equipment Regulations 1998 (PUWER) requires employers to provide equipment that is safe for use at work.

The general Regulations do not specifically limit exposure levels to optical radiation. However, for many years, the Guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) have been accepted as good practice.

3 NEW REGULATIONS

New specific legislation – The Control of Artificial Optical Radiation at Work Regulations (CAORWR) 2010 [2] – has been introduced in the UK. These Regulations build on the general requirements of the existing safety legislation, described above. If you are already complying with existing legislation then it is likely that you will have little additional work to do to comply with the new Regulations.

The new Regulations essentially cover all optical radiations, other than those from the sun. However, it is important that employers concentrate any assessments on exposure scenarios that may present a risk of workers either exceeding the Exposure Limit Values (ELVs) or otherwise causing harm.

The Regulations do not cover exposure of the public, but the more general Management of Health and Safety at Work Regulations do.

The ELVs are identical to those published by ICNIRP. However, for the first time they will become legal limits, which should not be exceeded.

All workers need to be considered. The primary assessment is likely to be the responsibility of the organisation creating the risk, i.e. Entertainment Venues, Production Companies etc. The organisation responsible for the primary assessment will be required to share the assessment information with other employers and employees likely to be affected. This will include performers, stage crews and technical staff. It is recognised that there are many sources of optical radiation that clearly do not present a risk of harm. These are termed “trivial” sources and will usually include indicator lamps, venue general lighting and computer or phone screens.

Although lasers are covered by the Regulations, this document is limited to non-laser sources. Unlike non-laser sources, the main concern with lasers is the probability of exposure rather than the exposure level if an exposure takes place. For practically all entertainment lasers, worker exposure close to the laser source will be in excess of the ELVs and should be strictly managed.

Risk Assessment

If exposure to AOR has not been considered as part of a risk assessment under the MHSWR, the COARWR will require the employer to carry out a risk assessment to determine the risk to his employees and others from AOR sources and, where necessary, the employer will be required to measure the levels of exposure.

If the risk assessment demonstrates that the ELV will not be exceeded or adequate information obtained from the manufacturer, supplier of the lamp or lighting fixture demonstrates safe exposure, measurements will not be required. It is recommended that this condition is recorded even if no further action is required. Guidance is provided in Annex C on using manufacturer's data. Important information that is needed for the risk assessment is the likely closest exposure distance to a source and the likely maximum duration of exposure. A separate assessment may be required for the eye and the skin, although the eye is usually the critical organ.

There may be exposure scenarios that require special assessment or advice. These will include workers who appear to be particularly photosensitive

Minimising the Risk

The whole purpose of using artificial optical radiation in the entertainment industry is for illumination to enhance or depict elements of the production. However, it may be possible to reduce the risk of exceeding the ELVs through appropriate design and manufacture of the equipment and considered, planned, exposures (which may mean that the direct exposure of people is minimised).

An example of good design is to ensure that, for example, ultraviolet radiation is filtered from lamps where the ultraviolet radiation is not required. This approach is better than having to limit the duration of exposure of workers.

It may be appropriate to use barriers or signs to restrict access to areas where exposure to the light source could result in the ELV being exceeded.

Training may be appropriate to ensure that workers are aware of the outcome of the risk assessment and any measures needed to protect them.

Medicals

The COARWR require that health surveillance be considered as part of the control of exposure. It is very unlikely that workers in the entertainment industry will require routine health surveillance as a result of working with artificial optical radiation. However, if a performer or crew member is exposure to levels in excess of the ELV, then a medical examination should be made available to them.

4 RISK ASSESSMENT ON THE CONTEXT OF LEGISLATION

Risk assessment is a requirement of the Management of Health and Safety at Work Regulations and new CAORWR 2010. CAORWR states that "*any risk of adverse health effects to the eyes or skin of employees as a result of exposure to artificial optical radiation which is identified in the revised risk assessment is eliminated or reduced to a minimum*".

The approach is based on the European Agency for Safety and Health at Work stepwise approach to risk assessment:

Step 1. Identifying hazards and those at risk

Step 2. Evaluating and prioritising risks

Step 3. Deciding on preventive action

Step 4. Taking action

Step 5. Monitoring and reviewing

Risks may be different in different stages of the life cycle of luminaires, e.g. normal use, maintenance or servicing.

Optical radiation hazards that should be considered in the entertainment environment are:

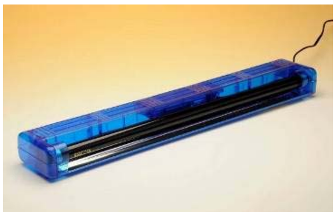
Actinic UV	Majority of lamps emits UVR	Not required in entertainment, at all, and should be filtered out
UVA	Majority of lamps emits UVR	Not required for illumination and should be filtered out
		May be required for special effects, e.g. fluorescence – hazard can't be eliminated for this application
Blue Light	Majority of luminaires emit visible light	Required for visual effects and illumination – hazard can't be eliminated for this application

Hazards may exist but what about risk?

The Regulations require either the elimination or minimisation of the risk of overexposure but not necessarily the elimination of the optical radiation.

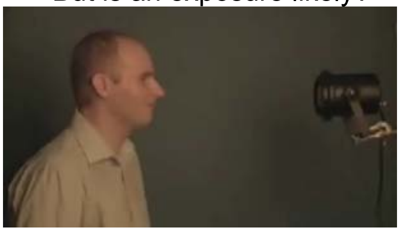
Spotlamp: emits UVA *AND* visible light

Blacklight: emits UVA only



UVA hazard level from these two sources is similar and UVA exposure limit from these two sources may be exceeded in ~ 1h, depending on distance from the source.

The same hazard level, the same position, the same person.
But is an exposure likely?



Very bright; exposure is avoided due to aversion response

No visible light emitted, no aversion response at all

Exposure is unlikely: risk is low

Exposure is likely: risk is high

Likelihood of risks

Actinic UV	
Likelihood of risk	**May be high**: hazardous for the eye and skin
What to do?	Not required in entertainment lighting and should be filtered out at luminaires *Risk could be and should be minimised by elimination of the hazard*
UVA: illumination and visual effects	
Likelihood of risk	**May be high** in peripheral vision and for low visual brightness sources For intense sources, direct intra-beam viewing should be prevented by aversion response to bright light
What to do?	Not required for illumination and visual effects; should be filtered out at luminaires *Risk could be and should be minimised by elimination of the hazard*
UVA: special effects	
Likelihood of risk	**May be high**: aversion response is compromised by very low visual brightness of special effect sources
What to do?	Requires detailed risk assessment Hazard can not be eliminated and exposure should be controlled by limiting exposure duration and/or accessible distance UV blocking eyewear should be used when exposure above the Exposure Limit is unavoidable
Blue Light hazard: white light sources	
Likelihood of risk	**Low**: If illuminance <1000 lx, hazard level is below Exposure Limit (see Annexes for details) If illuminance >1000 lx, aversion response to bright light should prevent extended ocular exposure
What to do?	No actions required for normal use Warning *Don't stare into the luminaire* may be recommended as precautionary measure for very bright sources
Blue Light hazard: single colour light sources	
Likelihood of risk	*Blue single colour luminaires* **May be high:** Hazard level may be high and aversion response could be compromised due to low visual brightness *Red and Green single colour luminaires* **Low:** For low visual brightness, hazard level is below Exposure Limit For high visual brightness, aversion response to bright light should prevent extended ocular exposure
What to do?	*Blue single colour luminaires* Detailed risk assessment may be required Warning *Don't stare into the luminaire* may be recommended as a precautionary measure

5 SUB-ELV EXPOSURES

ELVs are considered to be levels of exposure which, if not exceeded, will not result in adverse health effects. *However, there are exposure scenarios below the ELV that may cause concerns, especially for visible light.*

Flashing lights

Flashing lights are known to be a risk factor for photo-induced epilepsy.

►Keeping flash rates below 5 hertz reduces the risk considerably;

►Flash rates above about 30 hertz are also less likely to trigger an attack.

It is important to consider the total flash rate from all sources in the worker’s field of view. Guidance from the Health and Safety Executive recommends that strobe lights, for example, should be synchronised.

Distraction, dazzle and afterimages

Light can cause distraction, dazzle and afterimages. The impact of this will depend on the activity the performer/crew member was carrying out at the time of exposure. In particular, it is important to consider anyone who are suddenly exposed to bright lights while carrying out safety critical operations, such as working at height. Performer exposure during a performance should be considered by the lighting designer and production crew and measures to control any safety issues taken at rehearsals.

Illuminance ratio

It is also suggested that illuminance ratios should be considered. An example would be a performer lit with a follow-spot. It is important that the light level outside of the lit area is not lower than about a factor of ten to minimise problems with not being able to see when the follow-spot is directed elsewhere.

In practice, it may not be always possible. Therefore, actions should be taken to minimise the risk of falls, trips or slips due to temporary visual impairment.

6 PROPOSED STRATEGY FOR MANAGEMENT OF RISKS TO OPTICAL RADIATION

6.1 White light sources

Actinic UV and UVA

Not required for illumination and visual effects

Hazards should be eliminated by filtering at luminaire

Blue Light hazard

Hazard can't be eliminated in illumination

Low risk:

<1000 lx, hazard level is below Exposure Limit

>1000 lx, aversion response to bright light should prevent extended ocular exposure

Risk assessment options

If

No UV
Illuminance <1000 lx
No heat

or

No UV
Illuminance >1000 lx but extended ocular exposure is unlikely
No heat

or

No UV
Luminance $<10^4$ cd/m^2
No heat

∇

No risk of overexposure in 8 h and no further actions required

6.2 Single colour luminaires, Red and Green

Actinic UV and UVA

Not required for illumination and visual effects

Hazards should be eliminated by filtering at luminaire

Blue Light hazard

Hazard can't be eliminated in illumination

Low risk:

For low visual brightness, hazard level is below Exposure Limit

For high visual brightness, aversion response to bright light should prevent extended ocular exposure

Risk assessment options

If

No UV
Luminance <10^4 cd/m^2
No heat

∇

No risk of overexposure in 8h and no further actions required

6.3 Single colour luminaires, Blue

Actinic UV and UVA

Not required for illumination and visual effects

Hazards should be eliminated by filtering at luminaire

Blue Light hazard

Hazard can't be eliminated in illumination

Hazard level may be high and aversion response could be compromised due to low visual brightness

- Detailed risk assessment may be required
- Warning *Don't stare into the luminaire* may be recommended as a precautionary measure

6.4 Special effects UVA luminaires

Actinic UV

Actinic UV is not required and actinic UV hazard should be eliminated by filtering at luminaire

UVA

UVA hazard can not be eliminated and risk may be high: aversion response is compromised by very low visual brightness of special effect sources

- Detailed risk assessment is required
- Exposure should be controlled by limiting exposure duration and/or accessible distance

- UV blocking eyewear should be used when exposure above Exposure Limit is unavoidable

7 CONCLUSIONS

If a suitable and sufficient assessment of the risks from artificial optical radiation have already been carried out under the MHSWR, then no further action is required under the new Regulations.

Many of the light sources will result in exposures well below the ELVs in the Regulations and can be considered trivial.

Manufacturer’s data may assist in establishing where there is a risk of exceeding the ELV at locations, and for durations, where workers are likely to be exposed.

8 ACKNOWLEGEMENTS

Authors of this report would like to thank:

Katarzyna Baczynska, Michael Higlett, Andy Pearson (HPA)

Don Hart (Sky) | Peter Roberts (Cameron Mackintosh)

Heather Squire | Wob Roberts

Martin Professional (Denmark) | Sarah Dickerson (NEC)

for their valuable contribution, expertise and support.

A special acknowledgement and thanks to Ron Bonner from PLASA for being the driving force and fantastic facilitator of this project.

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APPENDIX A Biological effects of optical radiation

The optical radiation spectrum is generally divided up, by wavelength, as follows:

Ultraviolet “C” (UVC)	100 – 280 nm
Ultraviolet “B” (UVB)	280 – 315 nm
Ultraviolet “A” (UVA)	315 – 400 nm
Visible light	380 – 780 nm
Infrared “A” (IRA)	780 – 1400 nm
IRB	1400 – 3000 nm
IRC	3000 – 1000000 nm (3 μm – 1 mm)

A1 THE EYE

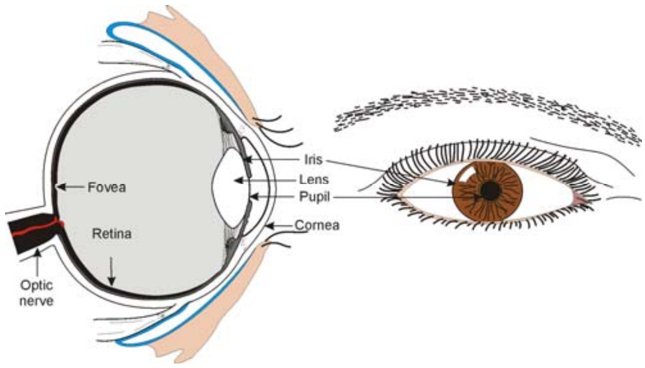


Figure A1. Structure of the eye

Light entering the eye passes through the cornea, aqueous homour, then through a variable aperture (pupil), and through the lens and vitreous to be focused on the retina. The optic nerve carries signals from the photoreceptors of the retina to the brain.

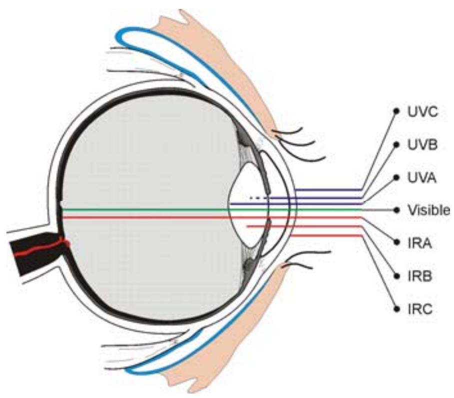
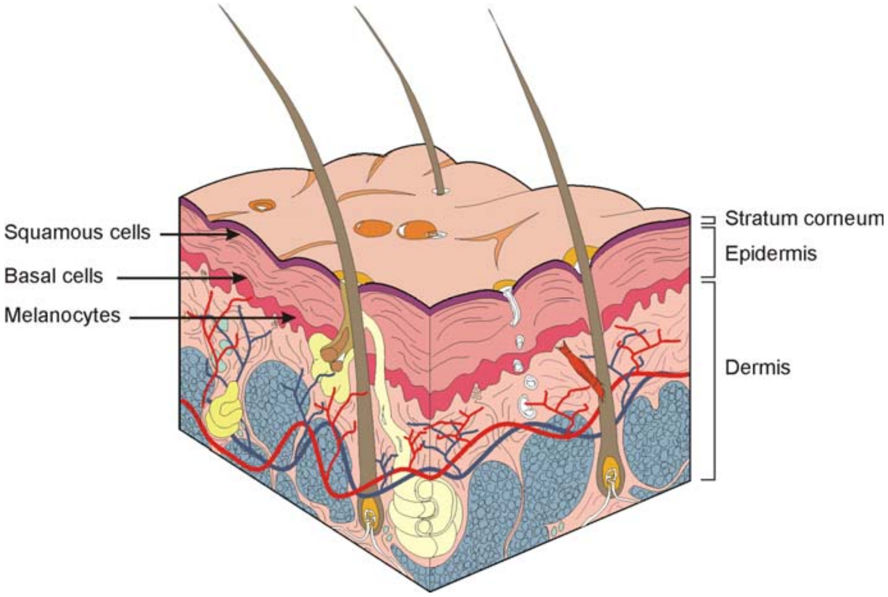


Figure A2. Penetration of different wavelengths through the eye

A2 THE SKIN

Figure A3. The structure of the skin



The outer layer of the skin, the epidermis, contains mainly keratinocytes (squamous cells) which are produced in the basal layer and rise to the surface to be sloughed off. The dermis is composed mainly of collagen fibres and contains nerve endings, sweat glands, hair follicles and blood vessels.

Figure A4. Penetration of different wavelengths through the skin

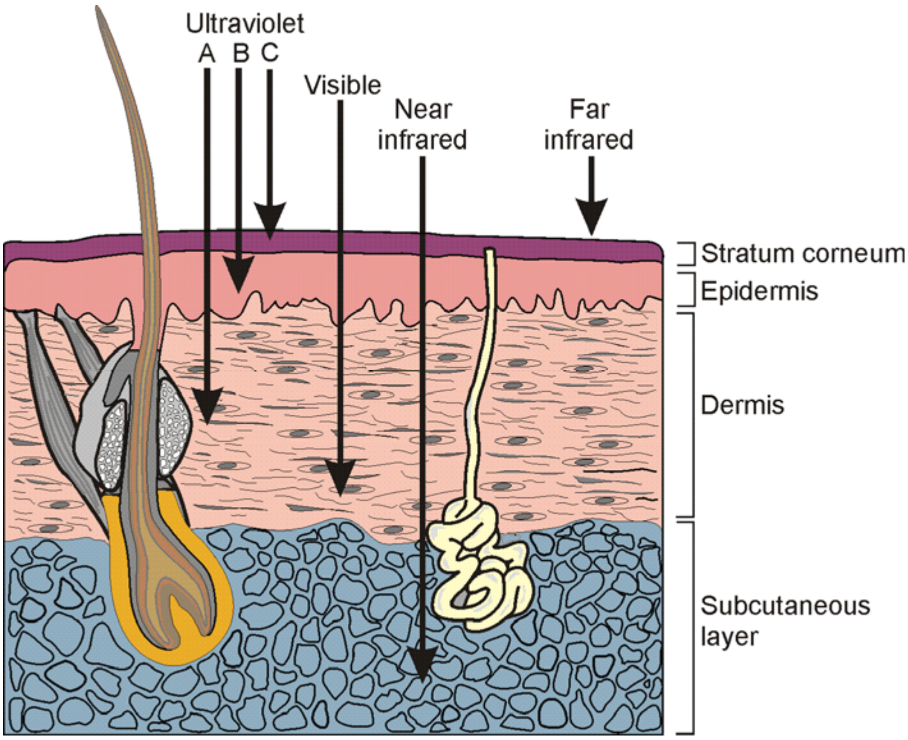


TABLE A1 Biological effects of optical radiation to the eye and skin

Wavelength, nm		Eye	Skin
100 – 280	UVC	Photokeratitis Photoconjunctivitis	Erythema Skin cancer
280 – 315	UVB	Photokeratitis Photoconjunctivitis Cataracts	Erythema Elastosis (photoageing) Skin cancer
315 – 400	UVA	Photokeratitis Photoconjunctivitis Cataracts Photoretinal damage	Erythema Elastosis (photoageing) Immediate Pigment Darkening Skin cancer
380 – 780	Visible	Photoretinal damage (Blue Light Hazard) Retinal burn	Burn
780 – 1400	IRA	Cataracts Retinal burn	Burn
1400 – 3000	IRB	Cataracts	Burn
3000 – 10^6	IRC	Corneal burn	Burn

A3 UVR

The biological effects of UVR can be divided into acute (rapidly occurring) and chronic (occurring as a result of prolonged and repeated exposures over a long time). It is generally the case that acute effects will only occur if the exposure exceeds a threshold level, which will usually vary from person to person.

Chronic effects often do not have a threshold below which they will not occur. As such, the risk of these effects occurring cannot be reduced to zero. The risk can be reduced by reducing exposure; observance of the Exposure Limits should reduce risks from exposure to artificial sources of optical radiation to levels below those which society has accepted with respect to exposures to natural optical radiation.

Biological effects on the skin

Excessive short-term exposure to UVR causes erythema - a reddening of the skin, and swelling. Symptoms can be severe, and the maximum effect occurs 8-24 hours after exposure, subsiding over 3-4 days with subsequent dryness and skin peeling. This may be followed by an increase in skin pigmentation (delayed tanning). Exposure to UVA radiation can also cause an immediate but temporary change in skin pigmentation.

Some people have abnormal skin responses to UVR exposure (photosensitivity) because of genetic, metabolic, or other abnormalities, or because of intake or contact with certain drugs or chemicals.

The most serious potential long-term effect of UVR is the induction of skin cancer. The non-melanoma skin cancers (NMSCs) are basal cell carcinomas and squamous cell carcinomas. They are relatively common in white people, although they are rarely fatal. Malignant melanoma is the main cause of skin cancer death, although its incidence is less than NMSC. Both acute burning episodes of sun exposure and chronic occupational and recreational exposure may contribute to the risk of malignant melanoma.

Chronic exposure to UVR can also cause photoageing of the skin. There is evidence suggesting that exposure to UVR can affect immune responses.

Biological effects on the eyes

UVR falling on the eye is absorbed by the cornea and lens. The cornea and conjunctiva absorb strongly at wavelengths shorter than 300 nm. UVC is absorbed in the superficial layers of the cornea and UVB is absorbed by the cornea and lens. UVA passes through the cornea and is absorbed in the lens.

Responses of the human eye to acute overexposure of UVR include photokeratitis and photoconjunctivitis (inflammation of the cornea and the conjunctiva, respectively), more commonly known as snow blindness, arc-eye or welder’s flash. Symptoms, ranging from mild irritation, light sensitivity and tearing to severe pain, appear within 30 minutes to a day depending on the intensity of exposure and are usually reversible in a few days.

Chronic exposure to UVA and UVB can cause cataracts due to protein changes in the lens of the eye. Very little UVR (less than 1% UVA) normally gets through to the retina due to absorption by the anterior tissues of the eye. However, there are some people who do not have a natural lens as a result of cataract surgery, and unless there is an implanted artificial lens which absorbs it, the retina can be damaged by UVR (at wavelengths as short as 300 nm) entering the eye. This damage is a result of photochemically produced free radicals attacking the structures of the retinal cells. The retina is normally protected from acute damage by involuntary aversion responses to visible light, but UVR does not produce these responses: persons lacking a UVR absorbing lens are, therefore, at higher risk of suffering retinal damage if working with UVR sources.

Chronic UVR exposure is a major contributor to the development of corneal and conjunctival disorders such as climatic droplet keratopathy (an accumulation of yellow/brown deposits in the conjunctiva and cornea), pterygium (an overgrowth of tissue which may spread over the cornea) and probably pinguecula (a proliferative yellow lesion of the conjunctiva).

A4 VISIBLE RADIATION

Biological effects on the skin

Visible radiation (light) penetrates into the skin and may raise the local temperature enough to cause burning. The body will adjust to gradual temperature rises by increasing blood flow (which carries heat away) and perspiration. If the irradiation is insufficient to cause an acute burn (in 10 s or less), the exposed person will be protected by natural aversion responses to heat.

For long exposure durations, heat strain from thermal stress (increased core body temperature) is the principal adverse effect. Although this is not specifically covered by the Regulations, ambient temperature and work load must be considered.

Biological effects on the eyes

Because the eyes act to collect and focus visible radiation, the retina is at greater risk than the skin. Gazing at a bright light source can cause retinal damage. If the lesion is in the fovea, e.g. if looking directly along a laser beam, severe visual handicap may result. Natural protective measures include an aversion to bright light: the aversion response operates in about 0.25 seconds; the pupil contracts and can reduce retinal irradiance by about a factor of 30; and the head may be turned involuntarily away.

Retinal temperature increases of 10 – 20 °C can lead to irreversible damage due to denaturation of proteins. If the radiation source covers a large part of the field of view so that the retinal image is large, it is difficult for the retinal cells in the central region of the image to shed heat quickly.

Visible radiation can cause the same type of photochemically induced damage as UVR (although, at visible wavelengths, the aversion to bright light can act as a protective mechanism). This effect is most pronounced at wavelengths around 435-440 nm, and so it is sometimes called the “blue-light hazard”. Chronic exposure to high ambient levels of visible light may be responsible for photochemical damage to the cells of the retina, resulting in poor colour and night vision.

Where radiation enters the eye in an essentially parallel beam (i.e. very low divergence from a distant source or a laser) it may be imaged onto the retina in a very small area, concentrating the power tremendously and resulting in severe damage. This focussing process could, in theory, increase the irradiance on the retina compared to that falling on the eye by up to 500,000 times. In these cases, the brightness can exceed all known natural and man-made light sources. Most laser injuries are burns: pulsed high peak power lasers can produce such a rapid rise in temperature that cells literally explode.

A5 IRA

Biological effects on the skin

IRA penetrates several millimetres into tissue, that is, well into the dermis. It can produce the same thermal effects as visible radiation.

Biological effects on the eyes

Like visible radiation, IRA is also focussed by the cornea and lens and transmitted to the retina. There, it can cause the same sort of thermal damage as visible radiation can. However, the retina does not detect IRA, and so there is no protection from natural aversion responses. The spectral region from 380 to 1400 nm (visible and IRA) is sometimes called the “retinal hazard region”.

Chronic exposure to IRA may also induce cataracts.

IRA does not have sufficiently energetic photons for there to be a risk of photochemically induced damage.

A6 IRB

Biological effects on the skin

IRB penetrates less than 1 mm into tissue. It can cause the same thermal effects as visible radiation and IRA.

Biological effects on the eyes

At wavelengths around 1400 nm, the aqueous humour is a very strong absorber; and longer wavelengths are attenuated by the vitreous humour, thus the retina is protected. Heating of the aqueous humour and iris can raise the temperature of the adjacent tissues, including the lens, which is not vascularised and so cannot control its temperature. This, along with direct absorption of IRB by the lens induces cataracts, which have been an important occupational disease for some groups, principally glass blowers and chain makers.

As for visible, IRA and IRB wavelengths, heat strain and discomfort from thermal stress must be considered.

A7 IRC

Biological effects on the skin

IRC penetrates only to the uppermost layer of dead skin cells (stratum corneum). Powerful lasers, which may be capable of ablating the stratum corneum and damaging underlying tissues, are the most serious acute hazard in the IRC region. The damage mechanism is mainly thermal, but high peak power lasers may cause mechanical/acoustic damage.

Biological effects on the eyes

IRC is absorbed by the cornea, and so the main hazard is corneal burns. The temperature in adjacent structures of the eye may increase due to thermal conduction, but heat loss (by evaporation and blinking) and gain (due to body temperature) will influence this process.

APPENDIX B Exposure Limit Values

The European Union Directive 2006/25/EC [1] lays down the minimum safety requirements regarding the exposure of workers to risks arising from artificial optical radiation. It places a responsibility on employers to assess exposure levels, adopt preventative measures and arrange for the provision of information and training for their workers. The Directive gives priority to reducing risks at source, through preventative measures related to work equipment design, procedure and methods. The Directive incorporates the ICNIRP Exposure Limit Values (***ELVs).*** The key requirements of the Directive have been incorporated into UK law through the Control of Artificial Optical Radiation at Work Regulations 2010.

The ELVs take account of the biological effectiveness of the optical radiation in causing harm at different wavelengths, the duration of exposure to the optical radiation and the target tissue.

The ELVs represent levels at which the International Commission on Non-Ionizing Radiation Protection (ICNIRP) considers most of the working population can be repeatedly exposed without suffering any acute adverse health effects and without noticeable risk of long term effects [6,7].

Most exposure limits are based on studies of thresholds for acute effects, and are derived from statistical consideration of these thresholds. Therefore, ***exceeding an exposure limit will not necessarily result in adverse health effects.*** The risk of an adverse health effect will increase as exposure levels increase above the exposure limit. The majority of effects will occur, in the healthy adult working population, at levels substantially above the limits.

People who are unusually photosensitive or exposed to photosensitising agents may suffer adverse effects at levels below the exposure limits; ELVs may not adequately protect these persons.

The ELVs are not intended to avoid chronic skin effects: the incidence of these effects will be reduced by virtue of prevention of acute effects and reduction in lifelong exposure.

It is necessary to know the wavelength range of the optical radiation before the correct ELV can be selected. It should be noted that more than one ELV may apply for a given wavelength range. The ELVs for laser radiation are generally simpler to determine because the emission is at a single wavelength.

The time duration when exposure level reaches ELV(s) is often termed as *maximum permissible exposure time (MPE time)*: for exposure durations shorter than MPE time there is no risk of overexposure.

The Directive includes a table of different exposure limits for different wavelengths and exposure durations. It is possible to select those limits that are likely to apply to the entertainment sector. The ELVs for the *eye* and *skin* considered applicable in entertainment are as follows:

Limit a

To protect the **cornea, conjunctiva and skin**, a maximum effective radiant UVR (180 – 400 nm) exposure for the eyes and skin within an 8 hour working day = 30 J m^{-2} (eff)*.

**Weighted with relative biological spectral effectiveness values published by the International Commission on Non-Ionizing Radiation Protection [6].*

If the effective irradiance E_{eff} at a given distance ***r*** is expressed in W m^{-2}, then the maximum permissible exposure (MPE) time, in seconds, = 30 J m^{-2} / $E_{eff.}$.

*If this is > 8 hours, there is no risk that the exposure limit will be exceeded at distance **r.***

Limit b

To protect the **eye lens**, a maximum radiant UVA (315 – 400 nm) exposure for the eyes within an 8 hour working day = 10 kJ m^{-2}.

If the effective irradiance E_{UVA} at a given distance ***r***, is expressed in W m^{-2} then the maximum permissible exposure (MPE) time, in seconds, = 10^4 J m^{-2} / E_{UVA}.

*If this is > 8 hours, there is no risk that the exposure limit will be exceeded at distance **r.***

ICNIRP luminance Limit

According to the ICNIRP, there is no need to carry out a full assessment for retinal hazards (limits *d* or *g*) from a “white light” lighting source which has a luminance < 10^4 cd m^{-2} .

**This guidance will not serve to assess risks from ultraviolet radiation emissions.*

If the source luminance exceeds 10^4 cd m^{-2}, the assessment must be repeated with sufficient data to allow for comparison with exposure limits *d* and *g.*

Limit d

To protect the **eye retina**, a maximum effective radiance (300 – 700 nm) for the eyes within an 8 hour working = 100 W m^{-2} sr^{-1}.

If the effective radiance, L_B, is less than the exposure limit, there is no risk of injury to the retina.

Limit g

To protect the **eye retina**, a maximum effective radiance (380 – 1400 nm) for the eyes within an 8 hour working = 2.8 x 10^7 / Cα.

The most restrictive exposure limit comes when α ≥ 100 mrad. In this case, Cα = 100 mrad and the exposure limit is 280,000 W m^{-2} sr^{-1}.

If the effective radiance, L_R, is less than the exposure limit, there is no risk of injury to the retina.

APPENDIX C Use of safety information

Assessment of the risk of personal exposures to optical radiation in very complex entertainment environments may be significantly simplified if safety information is available from luminaire manufacturers.

It is suggested that safety information for the luminaire should include hazard ratios for all applicable optical radiation hazards. It may compliment photometric diagrams and provide a simple correlation between illuminance level in lux and the hazard level. This Annex illustrates some examples of use of the safety information and presentation of hazard values.

If hazard ratios are known, detailed spectral measurements are not required for simplified assessments: hazard levels for each applicable hazard could be calculated from simple illuminance mapping.

The approach described in this Annex may not be applicable to UVA luminaires for special effects (e.g. blacklights) or single colour lighting, such as LED clusters.

C1 HAZARD RATIO

In the absence of screens or filters between the luminaire and the assessment position, the shape of the emission spectrum of the luminaire remains the same: the intensity changes with distance but the relative percentage of individual spectral regions remains the same – it is characteristic for this source and independent of the position.

Hazard ratios for the applicable optical radiation hazards are defined as:

Actinic UVR hazard:

$$\text{Hazard ratio, W/lm} = \frac{\text{Actinic UV hazard, W m}^{-2}}{\text{Illuminance, lx}}$$

Illuminance level to exceed Exposure Limit in 8h (30 000s):

$$\text{Illuminance, lx} = \frac{30\ (J\ m^{-2})}{(Hazard\ ratio\ (W/lm)) \times 30\,000\ s}$$

UVA hazard:

$$\text{Hazard ratio, W/lm} = \frac{\text{UVA hazard, W m}^{-2}}{\text{Illuminance, lx}}$$

Illuminance level to exceed Exposure Limit in 8h (30 000s):

$$\text{Illuminance, lx} = \frac{10^4\ (J\ m^{-2})}{(Hazard\ ratio\ (W/lm)) \times 30\,000\ s}$$

Blue Light hazard:

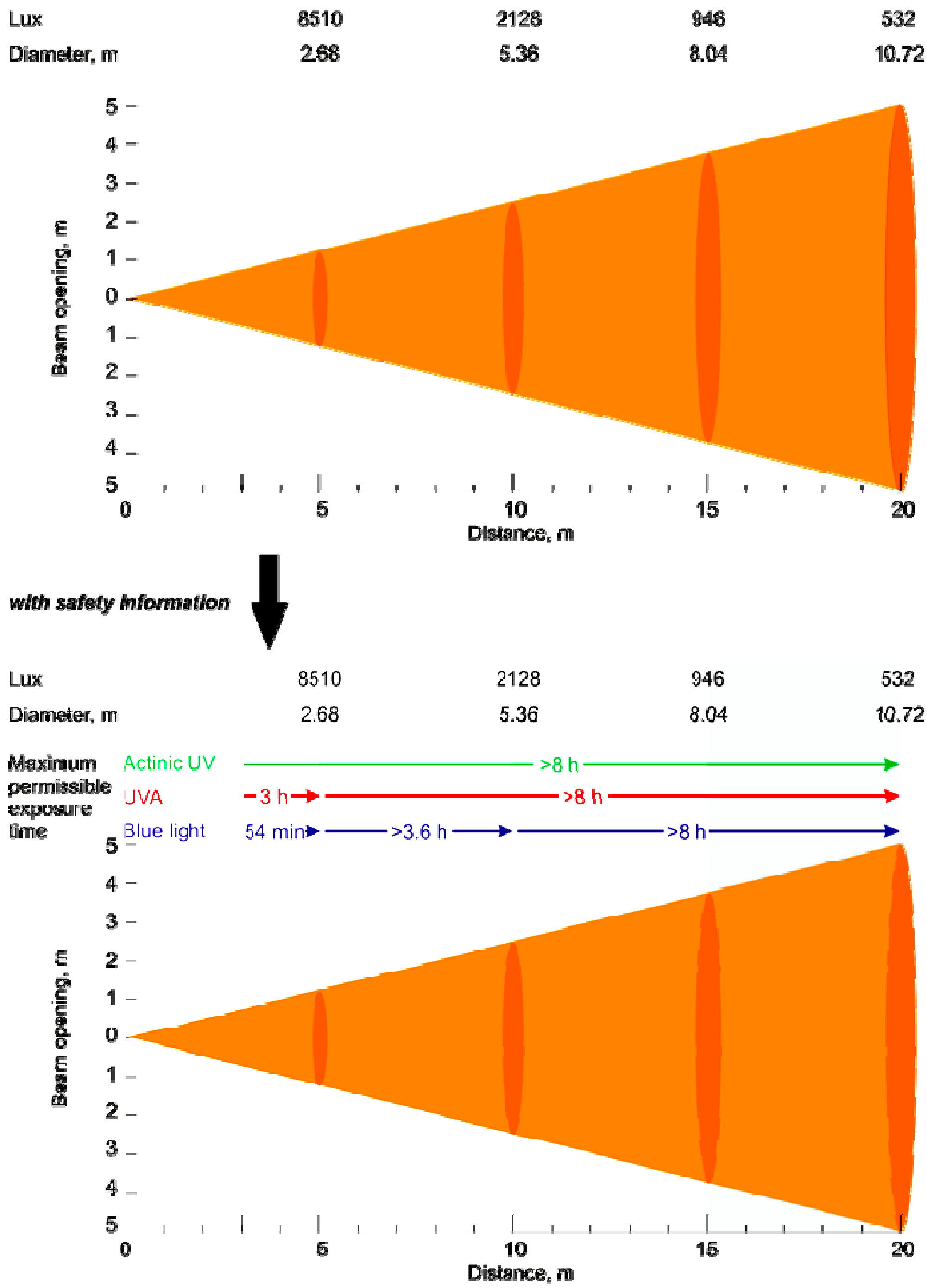
$$\text{Hazard ratio, W/lm} = \frac{(\text{Blue Light irradiance, W m}^{-2})}{\text{Illuminance, lx}}$$

Hazard ratios have very important practical implications: because hazard levels and illuminance are defined by the spectral irradiance, for *white light sources* the illuminance is unambiguously linked to the hazard level and could be used as guidance for the risk assessment.

C2 HOW SAFETY INFORMATION MAY BE INCLUDED IN THE PHOTOMETRIC DATA

Photometric information from the luminaire manufacturers is often presented as illuminance, in lx, for the range of typical distances.

Additional safety information could accompany photometric data to simplify risk assessment for the worst case exposure scenario – looking directly at the luminaire. Thus, if the maximum permissible exposure time at the given distance is >8h, there is no risk of overexposure. If the MPE time at this distance is less than 8h but exceeds the likely exposure duration, there is no risk of overexposure and no further analysis is needed.



Hazard ratio, W lm^{-1}: Actinic UV = $<10^{-7}$, UVA = 1.1 10^{-3}, Blue light = 3.6 10^{-4}

C3 SAFETY INFORMATION OF LAMPS

A similar approach could be applied to the lamps employed inside the luminaire, to guide the design of safety compliance of luminaires.

This information may be particularly useful because a very wide range of luminaires in entertainment incorporate a much smaller choice of lamps. Lamp data could be used for rough guidance if safety information of the luminaire is not available or assessment of exposure from multiple sources is required.

Hazard ratios and “safe” illuminance levels for actinic UV, UVA and Blue Light hazards were calculated for a range of widely used 200W, 400W, 575W, 1200W, 2500W and 4000W lamps. Spectral irradiance data are courtesy of General Electric, Philips and Osram.

Table C1. Safety information of lamps (without UV blocking additives in lamp envelope)

	Actinic UV		UVA		BL	
	hazard ratio, W/lm	illuminance to exceed ELV in 8h, lx	hazard ratio, W/lm	illuminance to exceed ELV in 8h, lx	hazard ratio, W/lm	illuminance to exceed ELV in 8h, lx
CSR 200/SE/HR	5.17E-05	19.3	1.01E-03	343.2	1.07E-03	933.5
CSR 400/SE/HR	1.50E-04	6.7	1.41E-03	245.4	1.16E-03	861.3
CSR 575/SE/HR	1.25E-04	8.0	1.42E-03	243.7	1.17E-03	857.9
CSR1200SE/HR	1.75E-04	5.7	1.55E-03	223.5	1.20E-03	832.6
Osram 73_05HMI1200W	No data				9.44E-04	1059.4
MSR1500	8.65E-05	11.6	9.98E-04	347.6	1.08E-03	923.2
CSR2500SE/HR	9.73E-05	10.3	1.29E-03	268.1	1.18E-03	844.8
CSR 4000SE/HR	1.58E-04	6.3	1.57E-03	220.4	1.34E-03	744.9

Although the wattage of the lamps varies considerably, the variation in safety values between individual lamps of the same type and/or manufacturer is not significant. *All these lamps will pose high risk of actinic and UVA hazards unless the accessible UV emission is filtered out.*

The hazard ratios of the lamps of different types, e.g. fluorescent or solid-state (LEDs, LUXIM’s LIFI), may be different.

It is reasonable to assume that the optics of the luminaire attenuates different parts of the visible emission spectrum proportionally, e.g. doesn’t have a great effect on the Blue Light hazard ratio and Blue Light safe-illuminance level: *an environment with the illuminance below 800-900 lx could be considered Blue Light safe for 8h exposure.* In reality, due to stronger attenuation of the blue part of the spectra, Blue Light hazard ratio is often lower than the values in Table C1 and the Blue Light safe illuminance is greater than 1000 lx.

UV blocking additives (UV filtered lamps) substantially reduce the accessible UV emission resulting in considerable reduction of Actinic UV and UVA hazard ratio: see Table C2 for identical wattage lamps with (CSR X/SE /HR /UV-C) and without (CSR X/SE /HR) UV blocking additives*.

UV filtration by the lamp envelope has little effect on Blue Light hazard ratio and Blue Light safe-illuminance level. Actinic UV and UVA hazard ratios of UVC filtered lamps of

* Spectral data courtesy of General Electric

different wattage are similar and could be used as guidance for the simplified risk assessment without the necessity for complex spectral measurement.

Table C2. CSR lamps with and without additional UV filtration

	Actinic UV		UVA		BL	
	hazard ratio, W/lm	illuminance to exceed ELV in 8h, lx	hazard ratio, W/lm	illuminance to exceed ELV in 8h, lx	hazard ratio, W/lm	illuminance to exceed ELV in 8h, lx
CSR 200/SE/HR	5.17E-05	19.3	1.01E-03	343.2	1.07E-03	933.5
CSR 200/SE/HR/UV-C	5.12E-07	1951.6	3.72E-04	932.5	1.06E-03	946.0
CSR 400/SE/HR	1.50E-04	6.7	1.41E-03	245.4	1.16E-03	861.3
CSR 400/SE/HR/UV-C	2.96E-07	3378.2	3.23E-04	1075.4	1.05E-03	949.4
CSR 575/SE/HR	1.25E-04	8.0	1.42E-03	243.7	1.17E-03	857.9
CSR 575/SE/HR/UV-C	1.18E-06	849.9	3.55E-04	977.2	1.05E-03	951.2
CSR1200SE/HR	1.75E-04	5.7	1.55E-03	223.5	1.20E-03	832.6
CSR1200/SE/HR/UV-C	2.48E-07	4035.7	2.69E-04	1288.1	1.08E-03	929.9
CSR2500SE/HR	9.73E-05	10.3	1.29E-03	268.1	1.18E-03	844.8
CSR2500/SE/HR/UV-C	9.43E-07	1060.0	3.19E-04	1088.8	1.08E-03	927.3
CSR 4000SE/HR	1.58E-04	6.3	1.57E-03	220.4	1.34E-03	744.9
CSR 4000SE/HR-UV-C	2.11E-06	473.2	4.00E-04	866.8	1.11E-03	904.6

For the moderate illuminance environments (~1000 lx), luminaires employing these filtered lamps would not present a risk of overexposure, even without further UV filtration by the luminaire optics: see Table C3.

Table C3. Maximum permissible exposure time for CSR lamps, based on most restrictive actinic UV hazard

Illuminance, lx	500	1000	2000	10000
CSR 200/SE/HR	19.3 min	9.7 min	4.8min	58s
CSR 200/SE/HR/UV-C	>>8h	>>8h	>8h	~1.5h
CSR 400/SE/HR	6.7min	3.3min	1.7min	20s
CSR 400/SE/HR/UV-C	>>8h	>>8h	>>8h	~2.8h
CSR 575/SE/HR	8min	4min	2min	24s
CSR 575/SE/HR/UV-C	>>8h	~7h	~3.5h	43 min
CSR1200SE/HR	5.7min	2.8min	1.4min	17s
CSR1200/SE/HR/UV-C	>>8h	>>8h	>>8h	~3.4h
CSR2500SE/HR	10min	5min	2.6min	31s
CSR2500/SE/HR/UV-C	>>8h	>8h	~4.4h	53min
CSR 4000SE/HR	6.3min	3.2min	1.6min	19s
CSR 4000SE/HR-UVC	~8h	~4h	~2h	24min

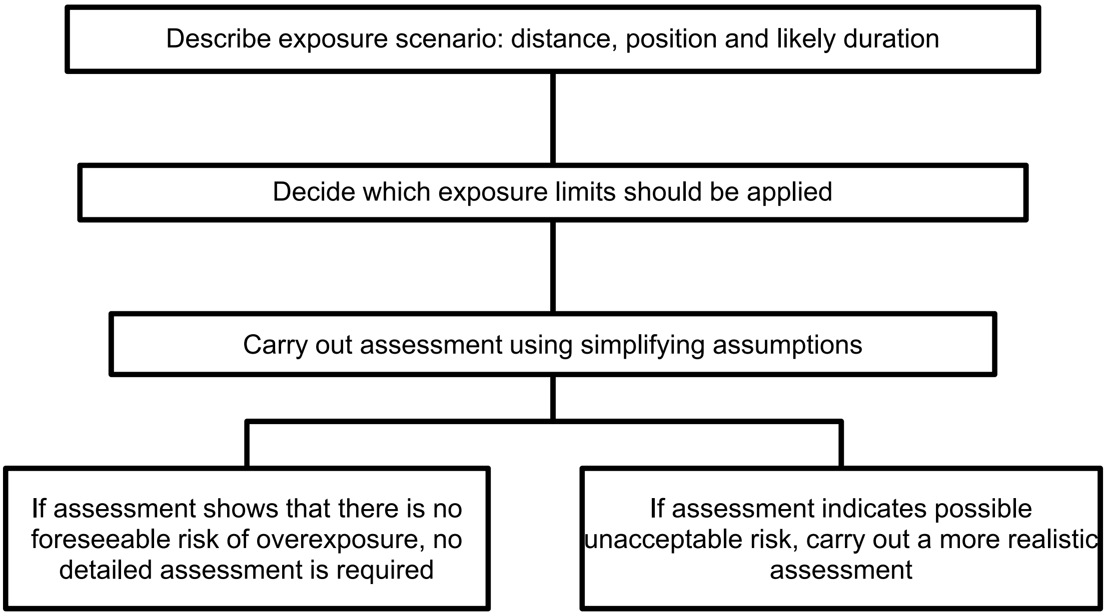
If safety information, e.g. hazard ratio values for applicable hazards, of lamps and luminaires is available from manufacturers, the risk assessment may be significantly simplified and detailed spectral measurements may not be required: the risk assessment could be carried out by evaluation of illuminance

APPENDIX D Introduction to practical assessment case studies

The entertainment environment often presents an extremely complex situation for the assessment of occupational exposures. Multiple illumination sources, continuously changing illumination conditions and people moving during performance add further complexity to the assessment.

Annexes D-H illustrate examples of practical risk assessments for a few typical entertainment establishments: TV News studio, large venues and theatre.

The following generic approach was used in all assessments:



Choice of Exposure Limits

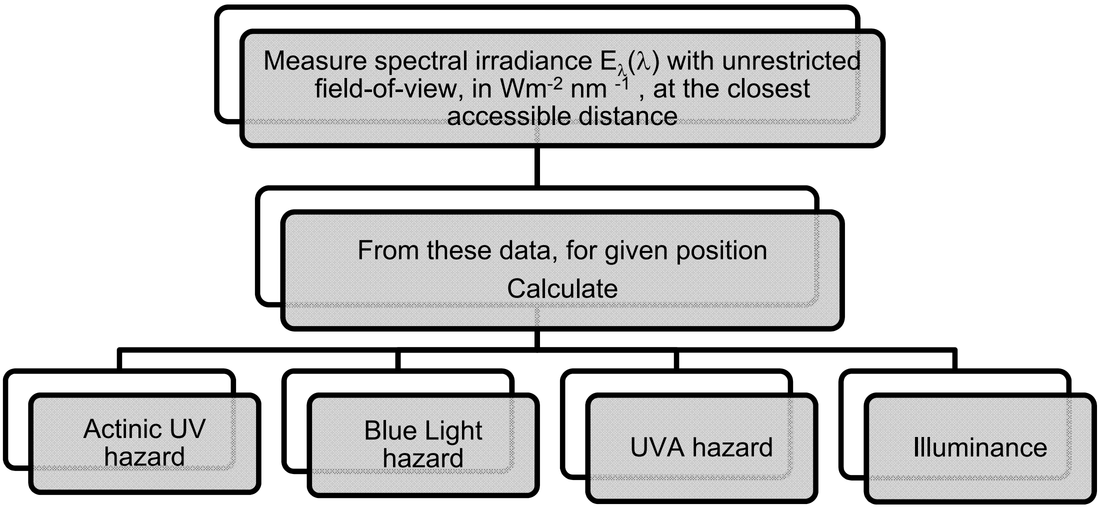
AORD Index	Wavelength range	ELV	Appropriateness
a	180-400 nm (actinic UV)	$H_{eff} = 30\ J\ m^{-2}$ *Spectrally weighted*	Yes, if source emits UVR
b	315 – 400 nm (UVA)	$H_{UVA} = 10^4\ J\ m^{-2}$	Yes, if source emits UVR
-	380-780 nm (ICNIRP luminance limit)	$10^4\ cd\ m^{-2}$ *Spectrally weighted*	Applicable for assessment of retinal hazards of “white” sources
d	300 -700 nm (Blue Light hazard) α ≥11 mrad and t > 10000 s	$100\ W\ m^{-2}\ sr^{-1}$ *Spectrally weighted*	Yes, if ICNIRP luminance level is exceeded
c	300 -700 nm (Blue Light hazard) α ≥11 mrad and t < 10000 s	$\frac{10^6}{t}\ W\ m^{-2}\ sr^{-1}$ *Spectrally weighted*	Yes, if ICNIRP luminance level is exceeded

If hazard ratios are known (e.g. from manufacturers' specifications), detailed spectral measurements are not required for simplified assessment: hazard levels for each applicable hazard could be calculated from simple illuminance mapping.

Simplifying assumptions:

- ►Closest accessible distance
- ►Looking directly at source
- ►Continuous 8h exposure
- ►Measurements with unrestricted field-of-view
- ►For Blue Light hazard, radiance is averaged over 0.01sr to account for eye movement during long exposure → *Blue Light ELV (Limit d) may be expressed as spectrally weighted irradiance of 1 W m^{-2}*

If measurements are required:



Calculations

Actinic UV hazard:

$$E_{eff} = \sum_{250nm}^{400nm} E_\lambda(\lambda) S(\lambda) \Delta\lambda \text{ , in W m}^{-2}$$

If actinic UV weighted irradiance < 0.001 W m^{-2}, Exposure Limit of 30 J m^{-2} will not be exceeded in 8h.

If actinic UV weighted irradiance > 0.001 W m^{-2}, calculate MPE time:

$$\text{MPE time: } MPE = \frac{30\,Jm^{-2}}{E_{eff}} \text{ , in seconds}$$

It should be emphasized that actinic UV is not required in entertainment and should be filtered out at luminaire; therefore, detailed analysis should not be needed.

UVA hazard:

$$E_{UVA} = \sum_{315nm}^{400nm} E_\lambda(\lambda)\Delta\lambda \text{ , in W m}^{-2}$$

If UVA irradiance < 0.347 W m^{-2}, Exposure Limit of 10 000 J m^{-2} will not be exceeded in 8h.

If UVA irradiance > 0.347 W m^{-2}, calculate MPE time:

$$\text{MPE time: } MPE = \frac{10000\,Jm^{-2}}{E_{UVA}} \text{ , in seconds}$$

Blue Light hazard:

$$Blue\ Light\ hazard, W\ m^{-2} = \sum_{300nm}^{700nm} E_\lambda(\lambda) B_\lambda(\lambda)\Delta\lambda$$

If Blue Light weighted irradiance < 1 W m^{-2}, Exposure Limit will not be exceeded in 8h.

If Blue Light weighted irradiance > 1 W m^{-2}, calculate MPE time:

$$MPE, s = \frac{10^4}{Blue\ Light\ hazard\ (W\ m^{-2})}$$

Illuminance:

$$\text{Illuminance, lux} = 683 \sum_{380nm}^{780nm} E_\lambda(\lambda) V_\lambda(\lambda)\Delta\lambda$$

where

$E_\lambda(\lambda)$ – spectral irradiance of the source;

$S(\lambda)$ - the UVR spectral weighting values [6];

$B(\lambda)$ – the Blue Light hazard spectral weighting values [7];

$V(\lambda)$ – the values of spectral luminous efficiency function [11];

$\Delta\tilde{\lambda}$ - the wavelength interval of the measurements.

If this simplified and over-conservative assessment shows that there is no foreseeable risk of overexposure, no detailed assessment is required.

If this simplified and conservative assessment shows that there is no foreseeable risk of overexposure, no detailed assessment is required. If the assessment indicates a possible unacceptable risk, a more realistic assessment should be carried out:

►Is 8h accumulative exposure at given position feasible? Is closest accessible distance realistic for 8h exposure?

►Is staring directly at the luminaire for 8h feasible and necessary? Will aversion response to bright light prevent extended viewing?

Realistic exposure duration

If the total foreseeable exposure duration within an 8h period at the closest accessible position is less than the most restrictive MPE time, there is no real risk of over-exposure and no further analysis is required.

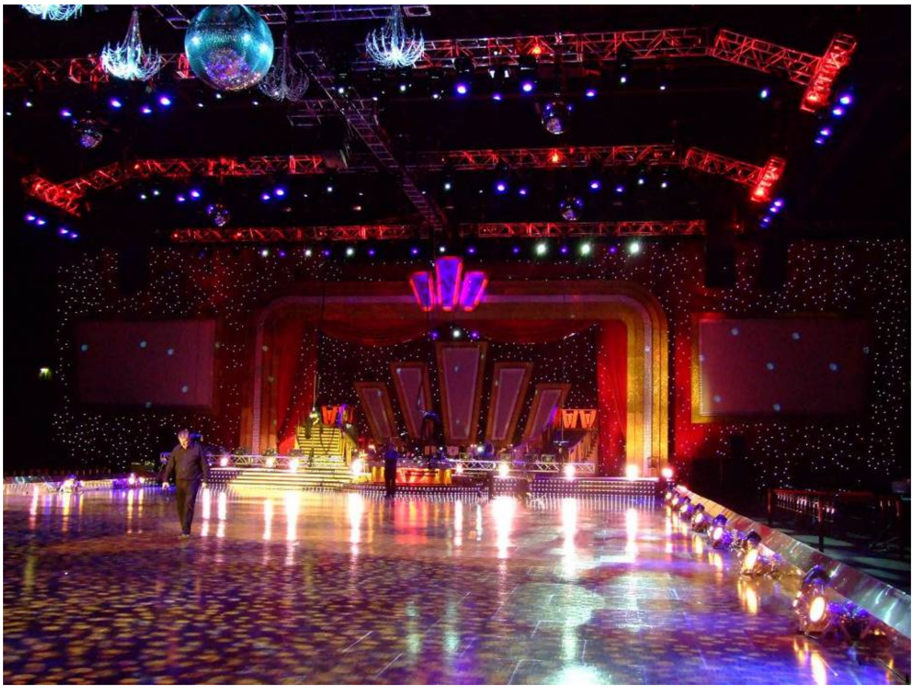
For the bright white light sources, the aversion response should prevent extended intra-beam viewing. However, aversion responses don't happen universally. The perceived brightness of non-white sources, in particular blue, may not be sufficient to trigger an aversion response.

Realistic illumination conditions

Assessment at different positions and with consideration of how the luminaire is viewed, e.g. staring directly at the source or looking away, could be done without further spectral measurements, by using hazard ratio values, "safe" illuminance levels (e.g. the level when applicable Exposure Limit will not be exceeded in 8h) and measured illuminance in lx. For the "safe" illuminance level, a detailed analysis is not needed: at these positions the applicable Exposure Limits will not be exceeded in 8h.

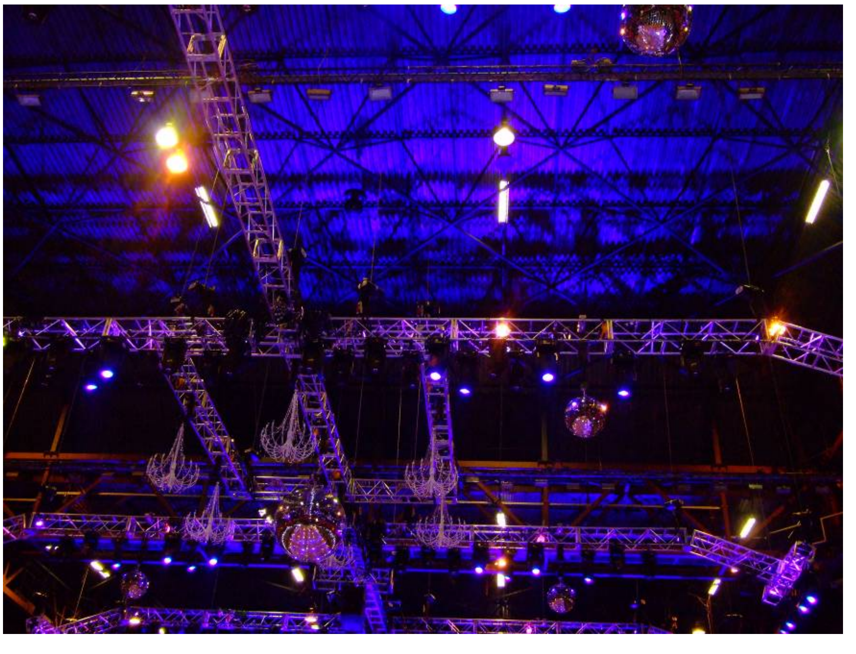
APPENDIX E Case study: stage and arena performance at large venue

NEC - Strictly Come Dancing, February 2009



The lighting design of Strictly Come Dancing at NEC Arena is by Mark Kenyon; equipment supplied by Sonalyst.

Lighting effects are provided by a range of luminaires deployed around the perimeter of the dance floor, on a stage and on a series of trusses above the arena.



Examples of assessed luminaires

VL 3500 Wash

1200W or 1500W double-ended short arc HTI

Clay Paky Stage Color 300
HTI 300 arc lamp

Clay Paky Alpha Profile 1200
1200W HMI lamp

Robe ColorWash 2500
Philips MSR Gold 1500W

Robe ColorSpot 700E
MSR Gold 700 lamp

Robe ColorWash 700E
MSR Gold 700 lamp

LED luminaires:
Blue
Green
Red
White (Red, Green and Blue single colour

23cm diameter cluster of Lumiled LEDs
Robert Julliat followspots

E1 EXPOSURE ON A DANCE FLOOR

Accessible emission was measured:

From luminaires on the floor around the perimeter at the shortest foreseeable distance of ~ 1.5m

From followspots above the arena

At eye level

Staring directly at the luminaire

At the centre of the beam

Luminaires are at maximum output settings

No colour filters used, where applicable

TABLE E1 Exposure on a dance floor

Luminaire	Followspots above arena			On a floor around perimeter	
	Robert Julliat, centre	Robert Julliat, left side	Robe ColorWash 2500	Clay Paky Stage Color 300	VL3500 Wash
			Actinic UV		
Hazard level			<< 0.1 mW/m^2		
			MPE time >> 8h		
			UVA		
Hazard level, W/m^2	0.1	0.01	0.07	0.74	1.09
MPE time		>8h		3.8h	2.5h
hazard ratio, W/lm	$5.1x10^{-5}$	$4.9x10^{-5}$	$8.9x10^{-5}$	$5.3x10^{-5}$	$7.2x10^{-5}$
illuminance level to exceed ELV in 8h	7 klx	7 klx	4 klx	6.5 klx	~5 klx
			Blue Light hazard		
Hazard level, $W/m^2 \cdot sr$	79.7	8.7	32.1	1300*	1227*
MPE time		> 8h		13 min	13.5 min
hazard ratio, W/lm	$3.9x10^{-4}$	$3.4x10^{-4}$	$4.3x10^{-4}$	$9.5x10^{-4}$	$8.1x10^{-4}$
illuminance level to exceed ELV in 8h, lx	2570	2970	2340	1058	1242
Measured illuminance, lx	1620	320	1100	27500	17200

** Measurements with unrestricted field-of-view*

Exposure of performers on a dance floor is not expected to present a risk of actinic UV hazard: actinic UV is substantially filtered out by output optics of luminaires.

Exposure of performers on a dance floor from followspots above the arena is not expected to present a risk of actinic UV, UVA or Blue Light hazards.

UVA hazard ratio is similar for all tested followspots; it varies between 4.9×10^{-5} and 9.1×10^{-5} and doesn't exceed 9.1×10^{-5} W/lm: 8h looking directly at followspot with the illuminance below 4 klx (*2.5 times higher than maximum measured value*) will not result in UVA overexposure.

Blue Light hazard level is well below 100 $W/m^2 \cdot sr$ for all tested followspots above the dance floor. Blue Light hazard ratio is similar for all tested followspots and doesn't exceed 4.3×10^{-4} W/lm: staring directly at the followspot with the illuminance below ~ 2.5 klx could be considered Blue Light safe for 8h exposure. Measured illuminance does not exceed ~1600 lx.

UVA hazard ratio is similar for Clay Paky Stage Color 300 and VL3500 Wash luminaires on a dance floor perimeter, with the maximum of 7.2×10^{-5} W/lm: 8h directly at these luminaires will not result in UV overexposure at the distances where the illuminance is below 5 klx.

Blue Light hazard level at 1.5m staring directly into the floor mounted luminaires significantly exceeds 100 $W/m^2 \cdot sr$ and MPE time is approximately 13 minutes. However, extended exposure from staring directly at extremely bright (17-27 klx at 1.5m) white light source is very unlikely: aversion response should prevent intra-beam viewing

The Blue Light safe illuminance level for 8h derived from maximum hazard ratio of 9.5×10^{-4} W/lm is ~ 1 klx for floor mounted luminaires. In practice, extended exposures above this level would be prevented by the aversion response – risk of overexposure is low, although the hazard level at close distance may be significant.

A solid angle of 0.01 sr (subtended angle of 110 mrad) when used in a simplified assessment of Blue Light radiance over-estimates the hazard level for large luminaires if measurements are carried out with an unrestricted (open) field of view.

This assessment relates to the foreseeable exposure of performers and crew and does not include operation, servicing or maintenance of luminaires. Personal exposures during operation of luminaires in close proximity, servicing or maintenance may require case-by-case detailed assessments.

E2 EXPOSURE ON A STAGE

Accessible emission was measured:

From LED luminaires on a floor at the shortest foreseeable distance of ~ 1.1m

From followspots above the stage (10-30m)

At the eye level

Staring directly at the luminaire

At the centre of the beam

Luminaires are at maximum output settings

No colour gels used in followspots

TABLE E2 Exposure on a stage: overhead followspots

Luminaires	Clay Paky Alpha Profile 1200	Robe ColorWash 2500	Robe ColorSpot 700	Robe ColorWash 700	VL3500 Wash	Three followspots from different luminaires	Robert Julliat
Actinic UV							
Hazard level	<< 0.1 mW/m^2						
MPE time >> 8h							
UVA							
Hazard level, W/m^2	0.007	0.5	0.022	0.19	0.03	0.08	0.002
MPE time	>>8h	~5.5h	>>8h				
hazard ratio, W/lm	1.7×10^{-5}	3.9×10^{-4}	7.8×10^{-5}	3.0×10^{-4}	7.2×10^{-5}	9.7×10^{-5}	5.1×10^{-5}
illuminance level to exceed ELV in 8h	>>10 klx	900 lx	~4.5 klx	~1100 lx	~5klx	~3.6 klx	~7klx
Blue Light hazard							
Hazard level, W/m^2·sr	33.4	122.8	22.1	51.6	46.3	43.4	14.7
MPE time	>8h	~2.2h	>8h				
hazard ratio, W/lm	8.4×10^{-4}	9.6×10^{-4}	7.6×10^{-4}	8.3×10^{-4}	7.2×10^{-4}	5.0×10^{-4}	8.7×10^{-4}
illuminance level to exceed ELV in 8h, lx	1190	1038	1317	1204	1391	2010	1150
Measured illuminance, lx	400	1270	290	620	645	875	170

Exposure of performers on a stage from followspots is not expected to present a risk of actinic UV, UVA or Blue Light hazards.

Actinic UV is substantially filtered out by output optics of followspots.

The UVA hazard ratio for the tested followspots varies between 1.7×10^{-5} and 3.4×10^{-4} W/lm: 5h looking directly at followspot will not result in UVA overexposure. In practice, 5h staring directly at the followspot is very unlikely and exposure from followspots could be considered as UVA-safe.

It should be noted that UVA hazard ratio in the tested Robe ColorWash (2500 and 700) is noticeably higher than in other measured followspots. It might be an indication of less efficient UVA filtration.

Blue Light hazard level is well below 100 W/m^2·sr for all tested followspots, with the exception of Robe ColorWash 2500.

The MPE time for the Blue Light hazard level of the Robe ColorWash 2500 exceeds 2h. In practice, staring directly at the followspot for 2h is unlikely and the exposure from followspots could be considered as Blue Light safe.

The Blue Light hazard ratio doesn't exceed 9.6×10^{-4} W/lm: staring directly at the followspot with the illuminance below ~ 1 klx could be considered Blue Light safe for 8h exposure.

This assessment relates to the foreseeable exposure of performers and crew and does not include operation, servicing or maintenance of luminaires.

Personal exposures during operation of luminaires in close proximity, servicing or maintenance may require case-by-case detailed assessment.

E3 LED LIGHTING

TABLE E3 Exposure on a stage: LED luminaires

LED Luminaire	Red	Green	Blue	White (R+G+B)
		Actinic UV		
Hazard level		<< 0.1 mW/m^2		
		MPE time >> 8h		
		UVA		
Hazard level, W/m^2		<0.001		
		MPE time >>8h		
		Blue Light hazard		
Peak wavelength, nm	640	520	450	450, 530 and 640
Hazard level, W/m^2·sr	7.7	97.4	6616*	1303*
MPE time	>8h		2.5 min	12.8 min
hazard ratio, W/lm	1.1×10^{-5}	1.0×10^{-4}	1.7×10^{-2}	7.8×10^{-4}
illuminance level to exceed ELV in 8h	>>10 klx	~10 klx	58 lx	1290 lx
calculated illuminance, lx	6840	9347	3812	16800
measured illuminance, lx	9000	11000	17100	18000

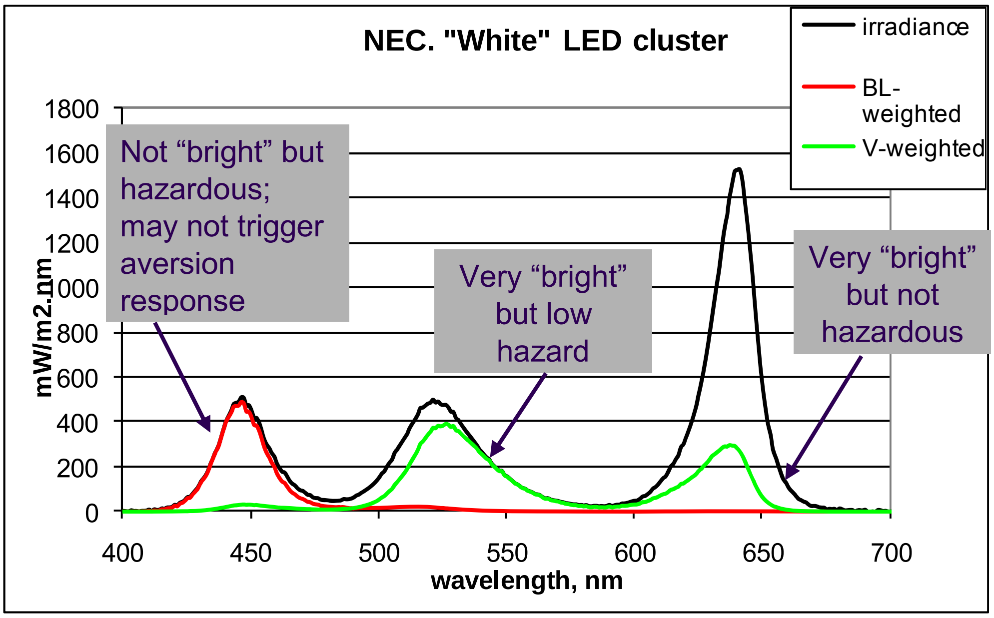
** Measurements with unrestricted field-of-view*

There is no risk of actinic UV or UVA hazards from LED spotlights.

The Blue Light hazard level at 1.1m staring directly into the floor mounted LED luminaires significantly exceeds 100 W/m^2·sr for Blue and White clusters: the MPE time is approximately 13 minutes for the White luminaire and less than 3 minutes for the Blue one. However, extended exposure from staring directly at an extremely bright White LED cluster is very unlikely: the aversion response should prevent intra-beam viewing. Due to low visual stimulus of blue light, the Blue LED cluster may not be perceived as very bright and not trigger the aversion response: intra-beam viewing is more likely and the risk of over-exposure is higher.

The Blue Light hazard level includes spectral weighting: light of different wavelengths have different potential to cause adverse effects; the peak of Blue Light hazard weighting is close to the peak emission of the Blue LED luminaire.

The Blue Light hazard ratio varies by 3 orders of magnitude for LEDs of different colours: from very low (1.1×10^{-5} W/lm) for Red LEDs to very high (1.7×10^{-2} W/lm) for Blue LEDs. The hazard ratio for White LEDs (7.8×10^{-4} W/lm) is close to that for other tested white-light sources.



The perceived brightness of a source depends on illuminance, spectrally weighted with the V(λ) luminous efficiency function, with its peak at 555nm. The Blue Light hazard level is spectrally weighted with the Blue Light hazard function, with its peak at 435-440nm. The red LED of the tested cluster is perceived as very bright (high illuminance level) but is Blue Light-safe (low Blue Light hazard level); whereas the Blue LED is not perceived as bright and may not trigger aversion response (low illuminance) but has a very high Blue Light hazard level.

The MPE time of ~ 2.5 minutes for the Blue LED cluster is short but it is substantially longer than the typical aversion response time of 0.25 s: an additional warning *Don't stare into the beam* may be sufficient to control exposure from this luminaire.

The solid angle of 0.01 sr (subtended angle of 110 mrad) used in the simplified assessment of the Blue Light radiance over-estimates the hazard level for large luminaires (subtended angle is 210 mrad in this case) if measurements are carried out with unrestricted (open) field of view.

Measurements of illuminance of "non-white" sources using broad-band lux meters might be inaccurate due to spectral sensitivity of the detecting system:

- There is satisfactory agreement between measured and calculated (from spectral measurements) illuminance levels for White and Green LEDs.
- There is ~ 30% difference for Red LEDs.
- Measured illuminance of Blue LEDs is ~ 4.5 times higher than illuminance calculated from spectral measurements.

This assessment relates to the foreseeable exposure of performers and crew and does not include servicing or maintenance of luminaires.

Personal exposures during operation of luminaires in close proximity, servicing or maintenance may require case-by-case detailed assessment.

E4 HIGH VISUAL CONTRAST CONCERN

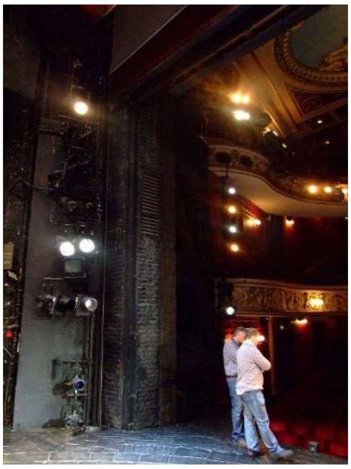
Although for the majority of the assessed illumination scenarios there is no foreseeable risk of overexposure, a significant difference between illuminance levels in some of the areas may cause dazzle, temporary visual impairment and non-optical safety concerns, such as slips, trips and falls. This may be particularly important when there are significant variations in the floor level: on a stage, steps or stairs.

APPENDIX F Case study: theatre

Les Misérables, Queen's Theatre, West End

Producer Sir Cameron Mackintosh

Lighting design by David Hersey



Accessible emission was measured:

At eye level

Staring directly at the luminaire

At the centre of the beam

Luminaires are at maximum settings

No colour gels used, where applicable

Examples of assessed luminaires

ETC Source Four

Ushio HPL 575W lamp

LED strip

R&V Beamlight Followspot

24V/1000W

F1 ETC SOURCE FOUR – AROUND AMPHITHEATRE

TABLE F1 ETC Source Four

Position	Right corner lamp	Two corner lamps	Two corner lamps, looking directly at	Two corner lamps, looking at ~ 45 degrees	Looking at audience	At the corner of the stage
distance	4m	4.5m	4.5m	1.5m	1.5m	6.2m
Actinic UV						
Hazard level	<< 0.1 mW/m^2					
MPE time >> 8h						
UVA						
Hazard level, W/m^2	0.029	0.024	0.024	0.0008	0.012	0.012
MPE time>>8h						
hazard ratio, W/lm	6.5×10^{-5}	5.15×10^{-5}	5.15×10^{-5}	3.9×10^{-5}	3.1×10^{-5}	3.1×10^{-5}
illuminance level to exceed ELV in 8h	> 5 klx					
Blue Light hazard						
Hazard level, W/m^2·sr	18.7	19.1	19.1	0.75	15.0	15.0
MPE time > 8h						
hazard ratio, W/lm	3.3×10^{-4}	3.2×10^{-4}	3.2×10^{-4}	2.9×10^{-4}	3.1×10^{-4}	3.1×10^{-4}
illuminance level to exceed ELV in 8h, lx	2356	2438	2438	2670	2560	2560
Measured illuminance, lx	440	466	466	21	285	385

Exposure of performers on a stage from ETC Source Four luminaires is not expected to present a risk of actinic UV, UVA or Blue Light hazards

The UVA hazard ratio is similar for all tested foreseeable illumination conditions and doesn't exceed 6.5×10^{-5} W/lm: 8h looking directly at luminaires with the illuminance below 5 klx (*order of magnitude higher than maximum measured value*) will not result in UVA overexposure.

Blue Light hazard level is well below 100 W/m^2·sr for all foreseeable illumination conditions from ETC Source Four.

Blue Light hazard ratio is similar for all tested followspots and doesn't exceed 3.3×10^{-4} W/lm: staring directly at the luminaire with the illuminance below ~ 2.5 klux could be considered Blue Light safe for 8h exposure. Measured illuminance does not exceed ~500 lx.

This assessment relates to the foreseeable exposure of actors and crew and does not include servicing or maintenance of luminaires.

Personal exposures during operation of luminaires in close proximity, servicing or maintenance may require case-by-case detailed assessments.

F2 LIGHTING AT THE PERIMETER OF THE STAGE

TABLE F2 Perimeter of the stage

Luminaire	LED strip	R&V Beamlight	R&V Beamlight, worst case
	Actinic UV		
Hazard level		$<< 0.1$ mW/m^2	
	MPE time >> 8h		
	UVA		
Hazard level, W/m^2	<0.001	0.178	0.176
MPE time >> 8h			
hazard ratio, W/lm	$<10^{-6}$	8.0×10^{-5}	7.8×10^{-5}
illuminance level to exceed ELV in 8h	>10 klx	>4 klx	
	Blue Light hazard		
Hazard level, W/m^2·sr	0.45	127.8	127.4
MPE time	>8h	~2h	~2h
hazard ratio, W/lm	8.0×10^{-4}	4.5×10^{-4}	4.5×10^{-4}
illuminance level to exceed ELV in 8h	~ 1000 lx	1745 lx	1765 lx
Measured illuminance, lx	4.4	2230	2248

Exposure of actors and supporting personnel from the lighting on a perimeter of the stage is not expected to present a risk of actinic UV, UVA or Blue Light hazards.

UVA hazard ratio doesn't exceed 8.0×10^{-5} W/lm: 8h looking directly at the these luminaires will not result in UVA overexposure.

Blue Light hazard level for R+V Beamlight followspot exceeds ELV of 100 W/m^2·sr.

MPE time for this luminaire is ~2h. In practice, staring directly at the followspot for 2h is unlikely and the exposure from this followspot could be considered as Blue Light safe.

This assessment relates to the foreseeable exposure of performers and crew and does not include servicing or maintenance of luminaires.

Personal exposures during operation of luminaires in a close proximity, servicing or maintenance may require case-by-case detailed assessments, especially if output optics (filters, lenses) are removed.

F3 WORST CASE ILLUMINATION SCENARIO: ALL LUMINAIRES ABOVE AND AROUND STAGE AND IN FRONT OF HOUSE ARE ON

TABLE F3 All luminaires ON

position	Worst case	Looking upstage	Looking horizontally	Looking downstage	Looking up	Worst case looking up
			Actinic UV			
Hazard level			<< 0.1 mW/m^2			
			MPE time >> 8h			
			UVA			
Hazard level, W/m^2	0.58	0.18	0.16	0.07	0.25	0.38
MPE time	~4.8h			>>8h		~7.4h
hazard ratio, W/lm	8.9×10^{-5}	9.9×10^{-5}	6.0×10^{-5}	9.6×10^{-5}	7.9×10^{-5}	7.8×10^{-5}
illuminance level to exceed ELV in 8h	3.9 klx	3.5 klx	5.8 klx	3.6 klx	4.4 klx	4.4 klx
			Blue Light hazard			
Hazard level, W/m^2·sr	458.6*	178.6*	122.4*	65.2	208.0*	321.5*
MPE time	~36 min	~1.5h	~2.3h	>8h	~1.3h	52 min
hazard ratio, W/lm	5.5×10^{-4}	7.9×10^{-4}	5.5×10^{-4}	5.5×10^{-4}	5.5×10^{-4}	5.5×10^{-4}
illuminance level to exceed ELV in 8h, lx	1400	~1000	2140	1160	1500	1500
Measured illuminance, lx	6.5 klx	1800	2600	750	3100	4800

** Measurements with unrestricted field-of-view*

Exposure of actors on a stage under a worst case exposure scenario is not expected to present a risk of actinic UV hazard: actinic UV is substantially filtered out by the output optics of luminaires.

The UVA hazard ratio is similar for all tested illumination conditions and doesn't exceed 9.9×10^{-5} W/lm: 8h looking directly at luminaires with the illuminance below 3.5 klx will not result in UVA overexposure.

Maximum permissible exposure time for the worst case exposure is almost 5h, with the assumption of staring directly into very bright, in excess of 3.5 klx, luminaire for 5h. It is very unlikely and the environment could be considered UVA-safe for actors on the stage.

Blue Light hazard level for the worst case exposure scenario staring directly into the luminaires may exceed 100 W/m^2·sr and the shortest MPE time is approximately 36 minutes. However, extended exposure from staring directly at extremely bright white light sources is very unlikely: aversion response should prevent intra-beam viewing.

Blue Light-safe illuminance level for 8h derived from maximum hazard ratio of 7.9×10^{-4} W/lm is ~ 1 klx. In practice, extended exposures above this level would be prevented by the aversion response – risk of overexposure is low, although the hazard level may be significant.

A solid angle of 0.01 sr (subtended angle of 110 mrad) used in the simplified assessment of Blue Light radiance over-estimates the hazard level for large luminaires if measurements are carried out with an unrestricted (open) field of view.

This assessment relates to the foreseeable exposure of actors and crew and does not include servicing or maintenance of luminaires.

Personal exposures during servicing or maintenance may require case-by-case detailed assessments, especially if output optics (filters, lenses) are removed.

Although for the assessed illumination scenarios there is no foreseeable risk of overexposure of actors and crew on the stage of Queen's Theatre, significant differences between illuminance levels may cause dazzle, temporary visual impairment and non-optical safety concerns, such as slips, trips or falls. This may be particularly important when there are significant variations in the floor level: on a stage, steps or stairs.

APPENDIX G Case study: stage performance at large venue

Snow Patrol, O2 Arena, 15 March 2009

The concert at the O2 Arena on 15 March 2009 was a part of *The Taking Back the Cities Tour* of Snow Patrol.

The lighting for the show was done by HSL which also supplied the crew. The lighting is based on the synergy of four visual media – lighting, digital lighting, video and movement. Lighting and visual Director is Davy Sherwin; live visual Director is Robin Haddow; Video Director is Blue Leach.

Lighting gear:

26-point Kinesys automation system

8 columns of Barco O-lite video screen, 13.5 ft high

4 Barco DLM 1200 digital moving lights

20 VariLite 3500 Wash fixtures

36 Martin Professional Atomic Colours

28 VariLite 3000 Spots

20 i-Pix BB4s

5 BB16 blinders

5 4-cell moles with scrollers

6 2-lites with “eyelids”

4 Robert Julliat Ivanhoe 2.5K followspots

2 WholeHog 3 consoles

Examples of assessed luminaires

VL 3000 Spot

1200W Short Arc Lamp

VL 3500 Wash

Double ended 1200W or 1500W short arc lamp

Robe ColorSpot 1200

MSR 1200W SA discharge lamp

i-Pix BB4

Customised lamina Titan RGB LEDs

Martin Professional Atomic 3000 Strobe

3000W long-life Xenon lamp

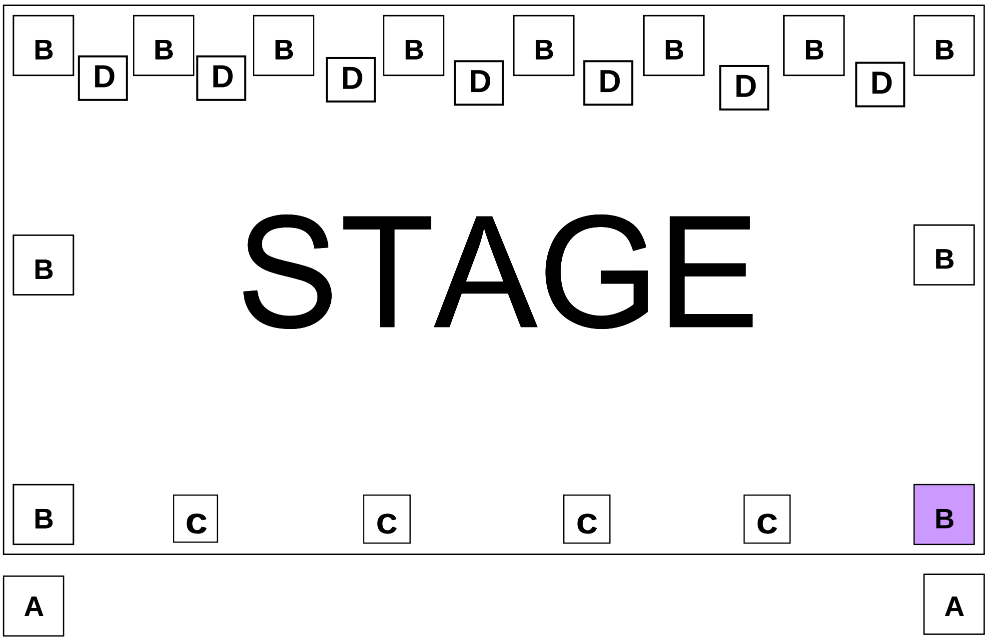
Gel string with 10 colours plus clear

Repetition rate 0-25 Hz

8 columns of Barco O-lite video screen, 13.5 ft high

2x4 Mole Scroller

G1 FLOOR MOUNTED LUMINAIRES AROUND PERIMETER OF THE STAGE



A: Barco DML 1200.
B: Robe ColorWash 1200E^{AT}
C: Lowel OMNI light
D: Mole Scroller (array of 2X4)

TABLE G1 Luminaires on a stage floor

Luminaire	Robe ColorWash 1200E^{AT}	Mole Scroller
Distance	4.6m, looking directly at	2.1m, looking directly at
	Actinic UV	
Hazard level	<< 0.1 mW/m^2	
	MPE time >> 8h	
	UVA	
Hazard level, W/m^2	0.016	0.27
	MPE time >> 8h	
hazard ratio, W/lm	2.8×10^{-4}	8.2×10^{-5}
illuminance level to exceed ELV in 8h	1230 lx	>4klx
	Blue Light hazard	
Hazard level, W/m^2·sr	5.1	112.7*
MPE time	>8h	~2.5h
hazard ratio, W/lm	9.0×10^{-4}	3.4×10^{-4}
illuminance level to exceed ELV in 8h, lx	1100	2970
Measured illuminance, lx	56	3350

** Measurements with unrestricted field-of-view*

Exposure of performers from the lighting on the perimeter of the stage is not expected to present a risk of actinic UV or UVA hazards.

Blue Light hazard level for the Mole Scroller exceeds 100 W/m^2·sr when looking directly at the luminaire at 2.1 m.

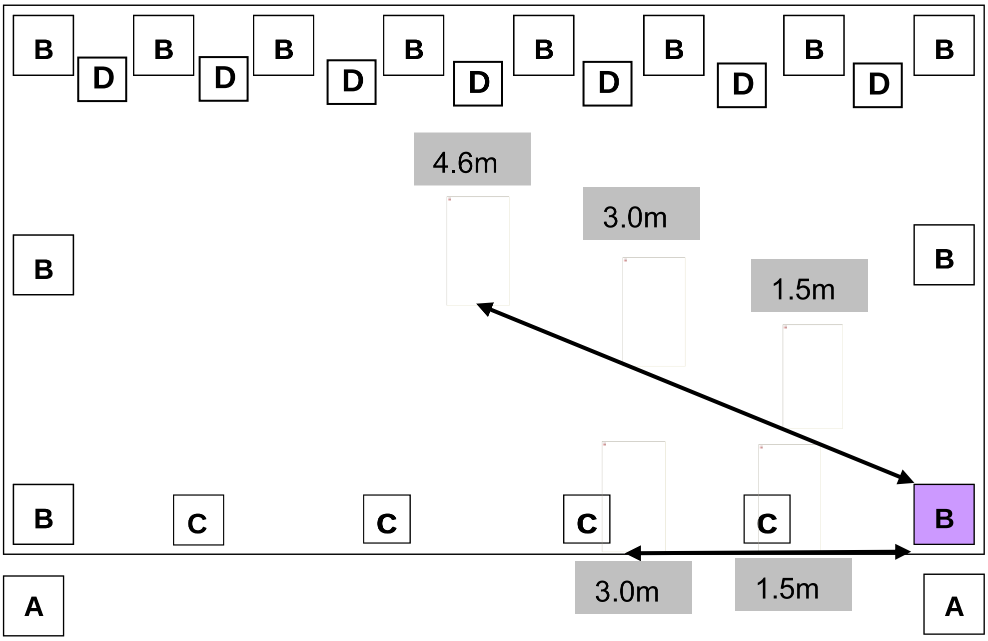
MPE time for this luminaire is ~2.5h. In practice, staring directly at the Mole Scroller for 2.5h, especially from such a short distance, is unlikely.

Assessment of Robe ColorWash 1200E^{AT} (highlighted as ■ on the diagram) was made at the distance of 4.6m at the expected position of musicians on a stage. The Blue Light hazard level at this distance is significantly lower than the limit of 100 W/m^2·sr. Although the hazard level may be different at closer distances (see below), exposure to this luminaire is not expected to present a risk of overexposure – extended direct viewing should be prevented by aversion response to bright white light.

This assessment relates to the foreseeable exposure of performers and crew and does not include servicing or maintenance of luminaires.

Personal exposures during operation of luminaires in close proximity, servicing or maintenance may require case-by-case detailed assessments, especially if output optics (filters, lenses) are removed.

Hazard ratio values of Robe ColorWash 1200E[AT] measured at 4.6 m (Table G1) and the illuminance measured by a lux meter were used to evaluate hazard level and maximum permissible exposure time for different exposure scenarios: looking at different directions and at range of distances from the luminaire.



UVA hazard level

$$\text{UVA hazard}, \frac{W}{m^2} = (\text{hazard ratio}, \frac{W}{lm}) \times (\text{illuminance}, lx)$$

UVA maximum permissible exposure time, s

$$\text{MPE time, s} = \frac{10^4 \ \frac{J}{m^2}}{\text{UVA hazard}, \frac{W}{m^2}}$$

Blue Light hazard level

$$\text{Blue Light hazard}, \frac{W}{m^2 sr} = (\text{hazard ratio}, \frac{W}{lm}) \times (\text{illuminance}, lx) / 0.01\, sr$$

If Blue Light hazard level <100 W/m^2·sr, there is no risk of overexposure

If Blue Light hazard level >100 W/m^2·sr, Blue Light maximum permissible exposure time, s

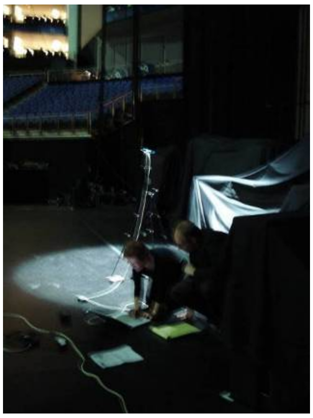
$$\text{MPE time}, s = \frac{10^6}{\text{hazard level}}$$

TABLE G2 Robe ColorWash 1200E[AT]

position	Measured illuminance, lx	UVA		Blue Light hazard	
		Hazard level, W/m^2	MPE time	Hazard level, $W/m^2 \cdot sr$	MPE time
4.6m, looking directly at luminaire	56	0.016	>>8h	5.1	>8h
4.6 m, looking downstage	35	0.01	>>8h	3.16	>8h
4.6m, looking upstage	6	0.002	>>8h	0.54	>>8h
4.6m, looking right stage	43	0.013	>>8h	3.9	>8h
4.6m, looking left stage	12	0.003	>>8h	1.1	>>8h
4.6m, looking down at floor	20	0.006	>>8h	1.8	>>8h
3.0m, centre of a stage, looking directly at	350	0.10	>>8h	31.6	>8h
3.0m, edge of the stage, looking directly at	6000	1.69	1.6h	541.6	30.8 min
1.5, centre of a stage, looking directly at	2300	0.65	4.3h	207.6	80.3 min
1.5m, edge of the stage, looking directly at	3600	1.01	2.7h	325.0	51.3 min

For the positions where illuminance does not exceed 1100 lx (highlighted in), no detailed analysis is needed – below this level UVA and Blue Light exposure limits are not exceeded in 8h, see Table G1.
UVA and Blue Light hazard levels for the realistic illumination conditions (not looking directly at the luminaire) are below applicable exposure limits.

The UVA and Blue Light hazard levels at 1.5m and 3.0m staring directly into the Robe ColorWash 1200E[AT] may exceed the Exposure Limits. The shortest MPE time is ~ 30 minutes: staring directly at very bright white light source for half an hour is very unlikely and the aversion response should prevent extended intra-beam viewing.



Although for the assessed illumination scenario there is no foreseeable risk of overexposure, the significant difference between illuminance when accidentally looking directly at Robe ColorWash 1200E[AT] and low ambient level (see Table above) may cause dazzle, temporary visual impairment and non-optical safety concerns, such as slips, trips or falls. This may be particularly important when there are significant variations in the floor level: on a stage, steps or stairs

G2 FOLLOWSPOTS ON TRUSSES

TABLE G3 Followspots on trusses, 7-10m above eye level: looking directly at – worst case

Luminaire	VL3000	VL3500	Robe ColorSpot 1200	I-Pix BB4	Atomic Strobe, repetition rate 25Hz	All light ON
Actinic UV						
Hazard level	<< 0.1 mW/m^2					
MPE time >>8h						
UVA						
Hazard level, W/m^2	0.056	0.56	0.46	0.001	0.034	1.42
MPE time	>>8h	~5h	~6h	>>8h		~2h
hazard ratio, W/lm	2.7×10^{-5}	9.4×10^{-5}	2.1×10^{-4}	6.7×10^{-6}	4.1×10^{-4}	2.9×10^{-4}
illuminance level to exceed ELV in 8h	12.6 klx	3.7 klx	1600 lx	52 klx	850 lx	4.2 klx
Blue Light hazard						
Hazard level, W/m^2·sr	152.8*	515.6*	204.2*	42.5*	7.1*	524*
MPE time	1.8h	32 min	1.4h	>8h		32 min
hazard ratio, W/lm	7.6×10^{-4}	8.7×10^{-4}	9.7×10^{-4}	3.0×10^{-3}	8.4×10^{-4}	1.1×10^{-3}
illuminance level to exceed ELV in 8h	1310 lx	1150 lx	1030 lx	335 lx	1190 lx	~ 1000 lx
Measured illuminance, lx	2000	5930	2100	142	85	4900

** Measurements with unrestricted field-of-view*

Exposure from the followspots is not expected to present a risk of actinic UV hazard; actinic UV is filtered out by the output optics and further attenuated by the long distance (7-10 m) from the luminaires.

UVA and Blue Light hazard levels for the worst case exposure scenario staring directly at the followspots may exceed the Exposure Limits. The shortest MPE time is ~ 30 minutes: staring up and directly at very bright white light source for half an hour is very unlikely - the aversion response should prevent extended intra-beam viewing.

Hazard ratio values of each luminaire and the illuminance measured by a lux meter were used to evaluate hazard level and maximum permissible exposure time when looking at different directions.

TABLE G4 Followspots: different conditions of viewing

Position	Measured illuminance, lx	UVA		Blue Light hazard	
		Hazard level, W/m^2	MPE time	Hazard level, W/m^2·sr	MPE time
VL3000					
Looking directly up	2000	0.056	>>8h	152.8	1.8h
Looking downstage	43	0.001	>>8h	3.3	>>8h
VL3500					
Looking directly up	5930	0.56	~5h	515.6	32 min
Looking downstage	5000	0.47	~5.9h	435.1	38min
Looking right	760	0.07	>>8h	66.1	>8h
Looking left	10	0.001	>>8h	0.87	>>8h
Looking upstage	28	0.003	>>8h	2.4	>>8h
Robe ColorSpot1200					
Looking directly up	2100	0.46	~6h	204.2	1.4h
Looking downstage	700	0.15	>8h	67.8	>8h
Looking right	9	0.002	>>8h	0.87	>>8h
Looking left	300	0.065	>8h	29.0	>8h
Looking down at floor	100	0.022	>>8h	9.7	>>8h
I-Pix BB4					
Looking directly up	130	0.001	>>8h	42.5	>8h
Looking downstage	60	<0.001	>>8h	17.9	>>8h
Atomic Strobe					
Looking directly up	85	0.034	>>8h	7.1	>>8h
Looking downstage	50	0.02	>>8h	4.2	>>8h
Looking right	1	<0.001	>>8h	0.08	>>8h
Looking left	10	0.004	>>8h	0.8	>>8h
Looking upstage	10	0.004	>>8h	0.8	>>8h
Looking down at floor	15	0.006	>>8h	1.2	>>8h
All followspots ON					
Looking directly up	4900	1.42	2h	524	32min
Looking horizontally, worst case	2650	77	3.6h	285	58 min
Looking downstage	780	0.23	>8h	84.0	>8h
Looking right	1030	0.30	>8h	110.9	~2.5h
Looking left	2450	0.71	3.9h	263.7	~1h
Looking upstage	50	0.014	>>8h	5.4	>>8h
Looking down at floor	700	0.2	>8h	75.3	>8h

For the positions (highlighted in) where illuminance does not exceed the maximum value specified in Table G3, no detailed analysis is needed – below this level UVA and Blue Light exposure limits are not exceeded in 8h.

UVA and Blue Light hazard levels for the realistic illumination conditions (not looking directly at the luminaire) are below applicable exposure limits.

UVA and Blue Light hazard levels when staring directly at some of the followspots may exceed the Exposure Limits. The shortest MPE time is ~ 30 minutes: staring directly at very bright white light source for half an hour is very unlikely - the aversion response should prevent extended intra-beam viewing.

G3 VIDEO SCREEN

Exposure from the Video Screen was measured at the centre of the stage, at a distance of 11m, looking directly at the Screen; Video Screen set All White at maximum output.

TABLE G5 Video Screen

	Actinic UV	UVA	Blue Light hazard
Hazard level	<< 0.1 mW/m^2	0.003 W/m^2	22. 6 $W/m^2 \cdot sr$
MPE time	>>8h	>>8h	>8h
Hazard ratio, W/lm	N/A	$7.7x10^{-6}$	$6.8x10^{-4}$
illuminance level to exceed ELV in 8h, lx	N/A	~45 klx	~1500 lx
Measured illuminance, lx		350 lx	

Exposure from Video Screen is not expected to present a risk of actinic UV, UVA or Blue Light hazards

G4 SUMMARY OF THE ASSESSMENT

Exposure of the performers during Snow Patrol concert at O2 Arena is not expected to present a risk of Actinic, UVA or Blue Light hazards

Actinic UV is filtered out by output optics of luminaires and further attenuated by the long distances from the luminaires.

UVA and Blue Light hazard levels for the realistic illumination conditions (not looking directly at the luminaire) are below applicable exposure limits, for all tested foreseeable exposure scenarios.

UVA and Blue Light hazard levels staring directly at some of the followspots may exceed Exposure Limits. The shortest MPE time is ~ 30 minutes; it is short but is substantially longer than typical aversion response time of 0.25 s: staring directly at very bright white light source for half an hour is very unlikely and the aversion response should prevent extended intra-beam viewing.

Although for the majority of assessed illumination scenarios there is no foreseeable risk of overexposure, significant differences between illuminance levels in some of the areas may cause dazzle, temporary visual impairment and non-optical safety concerns, such as slips, trips and falls. This may be particularly important when there are significant variations in floor level: on a stage, steps or stairs.

This assessment relates to the foreseeable exposure of performers and crew and does not include servicing or maintenance of luminaires.

Personal exposures for operation of luminaires in close proximity and during servicing or maintenance may require case-by-case detailed assessment.

APPENDIX H Case study: TV News studio

Sky News Studio A

Sky Studio A is a 600sqm TV News Room comprising 8 presentation areas and journalist work stations (Fig.H1):

- The principal zone is a 6 way anchor desk which rotates through 3 alignments during the production day, as shown in Fig.H2. The presenter and guest positions are lit by Strand Coolbeam Spotlights;
- Shoebox, a soft 1+3 area with a Letterman style desk and couch, is lit by Coolbeam Spotlights, 650W Fresnels, 1K Fresnels and Photon Beard TV fluorescents;
- Island, a 1+1 stand up area, is lit by Coolbeam Spotlights, 2K Fresnels and architectural Spotlights for walks;
- Video Wall, a walk and talk stage backed by a LED display wall, is lit frontally by Coolbeam Spotlights and upstage from 2K Fresnels;
- Mezanine, a traditional tungsten 650W Fresnels zone;
- Live Desk, a stand up position in the journalist area, is lit by a single 650W Fresnel;
- Journalist and dress lighting - by architectural Spotlights and CDM Codas;
- The set contains several LED and Neon strips built into the setting;
- The newsroom is ‘Live’ round the clock. However between 0900 – 1000 and 1300 – 1400 the News is broadcasted from the Live desk.

While Sky News is not currently using CDM profiles for artist lighting other than for walking shots and Journalists’ working lights, CDMs are more energy efficient compared to equivalent Tungsten luminaires: this is a technology that Sky is considering using more in the future.

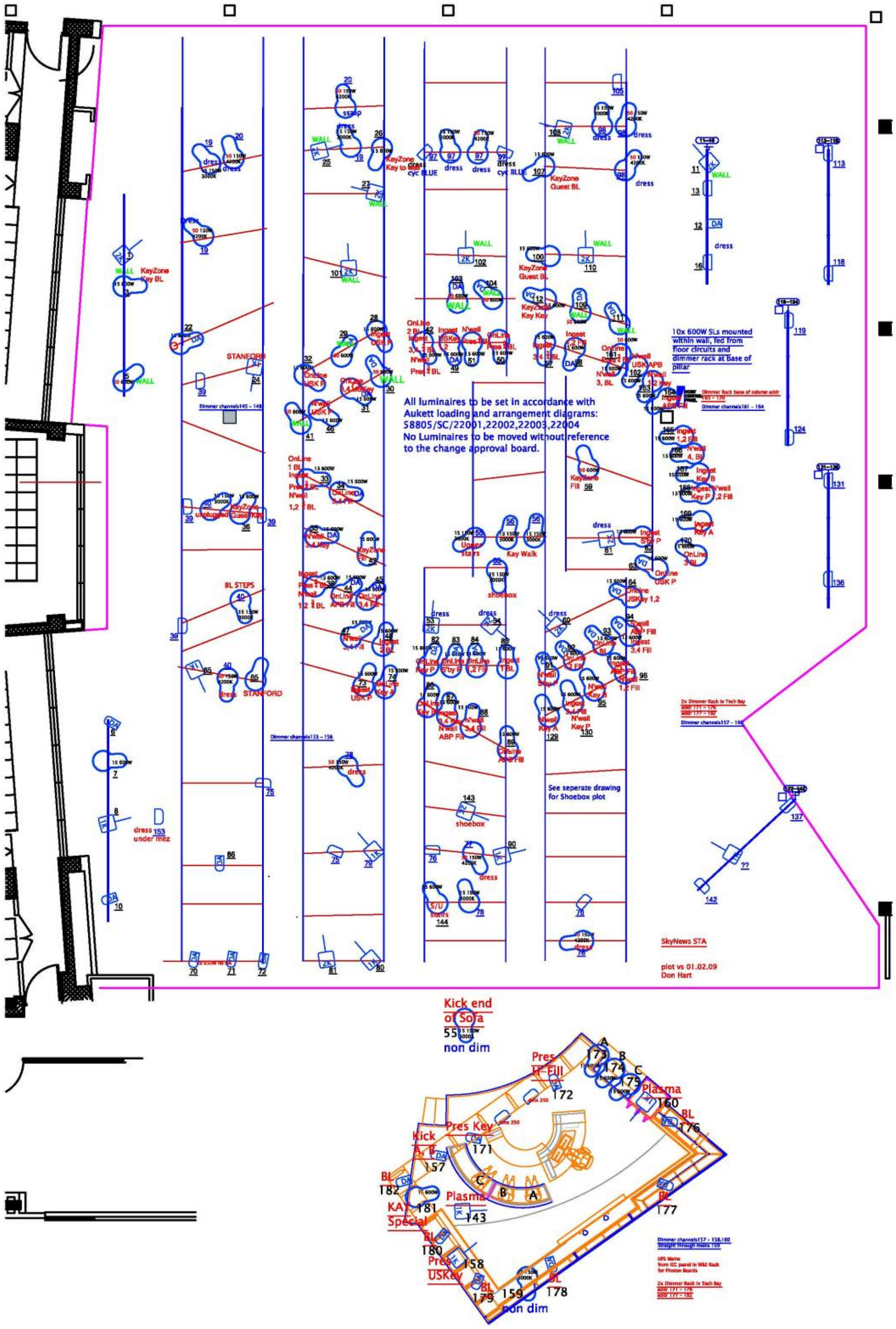


Figure H1. Principal layout of Sky Newsroom lighting

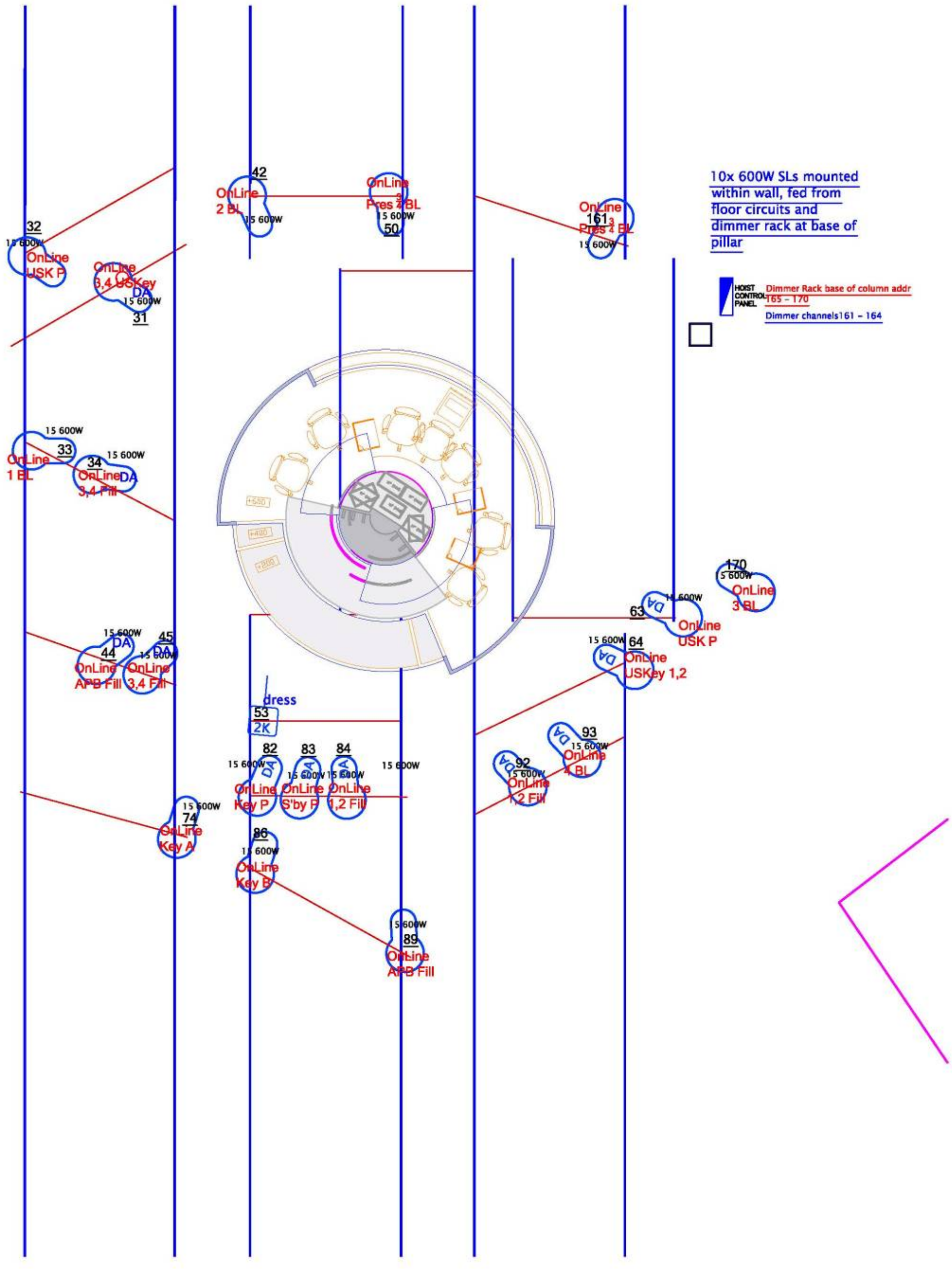


Figure H2. Principal layout of Sky on-line rotation Newsdesk

Summary of luminaires and lamp types of Sky News Studio A

Tungsten

Strand SpotLight Profile Coolbeam 15-32 degree zoom

600W GLB (GKV LongLife)

Strand SpotLight Profile Coolbeam 23-50 degree zoom

600W GLB (GKV LongLife)

Strand Bambino 2K TV Fresnels

2000W CP41

Strand 1K TV Fresnels

1000W CP40

Strand 650W Fresnel

650W CP89

Lamps are open or fitted with Rosco half Hanover frost, Atlantic Frost, brushed silk diffusion as required

Strand / Philips Architectural CDM fittings

Strand SpotLight Profile architectural 15-32 degree zoom

150W 3000K CDM-T 150W/830

Strand SpotLight Profile architectural 23-50 degree zoom

150W 4200K CDM-T 150W/942

Strand Coda asymmetric wash light

150W 4200K CDM-TP 150W/942

**This is a modification fitting a CDM-TP to a Coda 1000W single asymmetric module*

Lamps are operated open (with no diffusion) or fitted with Rosco half Hanover Frost, Atlantic Frost, brushed silk diffusion, eighth colour correction CTO as required

TV Fluorescent

Photon Beard Highlight 110 fitted with 2x 55W 2900K tubes

H1 NEWSDESK

Layout of the Newsdesk is shown in Fig.H2.

Accessible emission is measured at the eye level of the News presenter.

All luminaires are at operational settings.

Assessment made on assumption of worst case exposure for 8h.

TABLE H1 Newsdesk

Looking:	at camera	at lamp	left	down at display screen	left up	right up, at source	source behind, max	straight up
Actinic UV								
Hazard level	<< 0.1 mW/m^2							
	MPE time >> 8h							
UVA								
Hazard level, W/m^2	0.017	0.01	0.01	0.0036	0.0028	0.018	0.005	0.012
	MPE time >> 8h							
hazard ratio, W/lm	3.1×10^{-5}	2.0×10^{-5}	2.0×10^{-5}	1.5×10^{-5}	7.3×10^{-6}	2.2×10^{-5}	1.4×10^{-5}	2.2×10^{-5}
illuminance level to exceed ELV in 8h	>10 klx							
Blue Light hazard								
Hazard level, W/m^2·sr	18.2	17.5	17.5	8.8	11.3	25.9	13.8	10.1
	MPE time > 8h							
hazard ratio, W/lm	2.7×10^{-4}	2.6×10^{-4}	2.6×10^{-4}	3.0×10^{-4}	2.3×10^{-4}	2.6×10^{-4}	2.0×10^{-4}	2.1×10^{-4}
illuminance level to exceed ELV in 8h	2944 lx	3052 lx	3052 lx	2676 lx	3369 lx	3053 lx	3911 lx	3771 lx
Measured illuminance	535 lx	534 lx	534 lx	235 lx	380 lx	790 lx	380 lx	540 lx

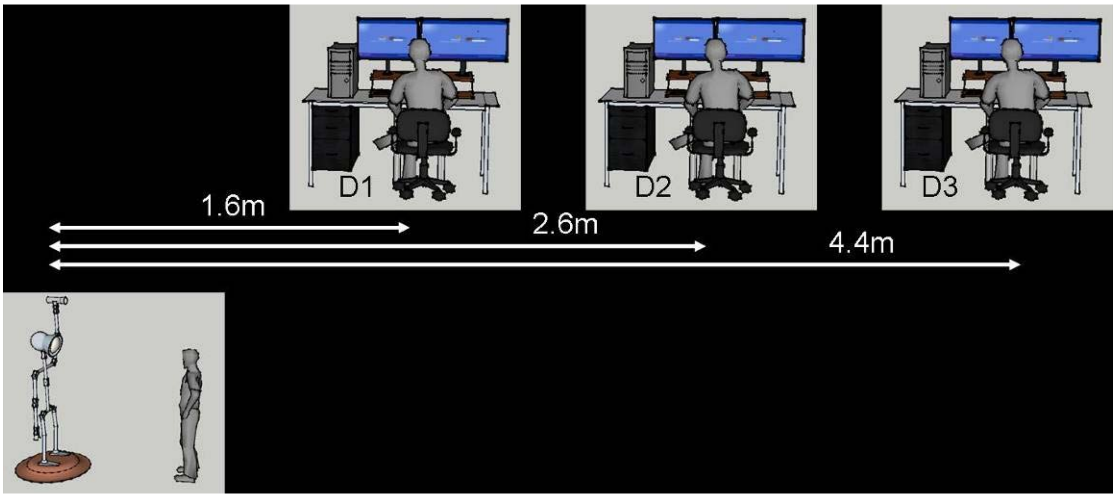
Exposure of News presenters during broadcasting from the Newsdesk is not expected to present a risk of actinic UV, UVA or Blue Light hazards.

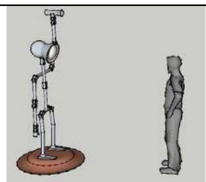
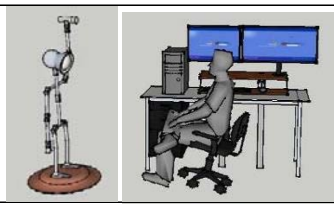
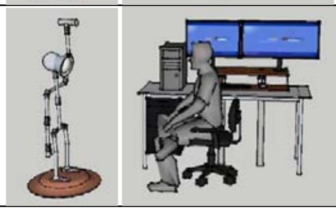
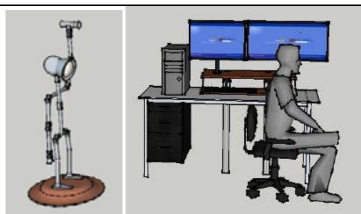
Actinic UV and UVA are substantially filtered out by the luminaires. UVA hazard ratio is similar for all tested illumination conditions and doesn't exceed 3.1×10^{-5} W/lm: 8h in the environment with the illuminance below 10 klx will not result in UV overexposure.

Blue Light hazard level is well below 100 W/m^2·sr for all foreseeable exposure conditions. Blue Light hazard ratio is similar for all tested exposure conditions and varies between 2.0×10^{-4} and 3.0×10^{-4} W/lm: illuminance below ~ 3klx could be considered Blue Light safe for 8h exposure. Measured illuminance at the foreseeable positions of News presenters does not exceed 800 lx.

This assessment relates to the exposure of News presenters and does not include servicing or maintenance of luminaires.

H2 STATION 11 – LIVE DESK



Exposure scenarios considered	
Worst case (over-conservative) – looking directly at CP89 luminaire; staring at luminaire for 8h	
For each workstation D1-D3:	
Staring directly at CP89 luminaire	
Looking horizontally towards CP89	
Looking at PC screen	
Looking away from CP89	

Sources of optical radiation:

- Fluorescent ceiling lighting;
- Strand 650W Fresnel, 650W CP89 – only during broadcasting, two intervals of 1h max during working shift;
- PC screens of journalists' desks D1-D3.

People who might be exposed:

- Presenter – looking at camera, away from CP89 luminaire;
- Journalists working at the desks D1-D3.

TABLE H2 Station 11: worst case exposure scenario - looking directly at CP89 luminaire

Position	Presenter	Desk D1	Desk D2	Desk D3
Actinic UV				
Hazard level	<< 0.1 mW/m^2			
MPE time >> 8h				
UVA				
Hazard level, W/m^2	0.042	0.037	0.014	0.0017
MPE time >> 8h				
hazard ratio, W/lm	$3.8x10^{-5}$	$3.5x10^{-5}$	$3.3x10^{-5}$	$9.98x10^{-6}$
illuminance level to exceed ELV in 8h	>9 klx			
Blue Light hazard				
Hazard level, W/m^2·sr	56.5	54.4	22.3	8.1
MPE time > 8h				
hazard ratio, W/lm	$4.0x10^{-4}$	$4.0x10^{-4}$	$3.95x10^{-4}$	$3.7x10^{-4}$
illuminance level to exceed ELV in 8h	1963 lx	1945 lx	1990 lx	2098 lx
Measured illuminance	1109 lx	1057 lx	444 lx	171 lx

Exposure of presenters and journalists during broadcasting from Station 11 Live Desk is not expected to present a risk of actinic UV, UVA or Blue Light hazards, even under worst case conditions of staring at the operating Strand 650 Fresnel luminaire for 8h.

It should be noted that total broadcasting time at Station 11 doesn't exceed 2h in any working day.

Actinic UV and UVA are substantially filtered out by the luminaires. UVA hazard ratio is similar for all tested illumination conditions and doesn't exceed $3.8x10^{-5}$ W/lm: 8h in the environment with the illuminance below 9 klx will not result in UV overexposure.

Blue Light hazard level is below 100 W/m^2·sr for the unlikely worst case staring directly at operating luminaire: such an exposure should be prevented by aversion response to the very bright light.

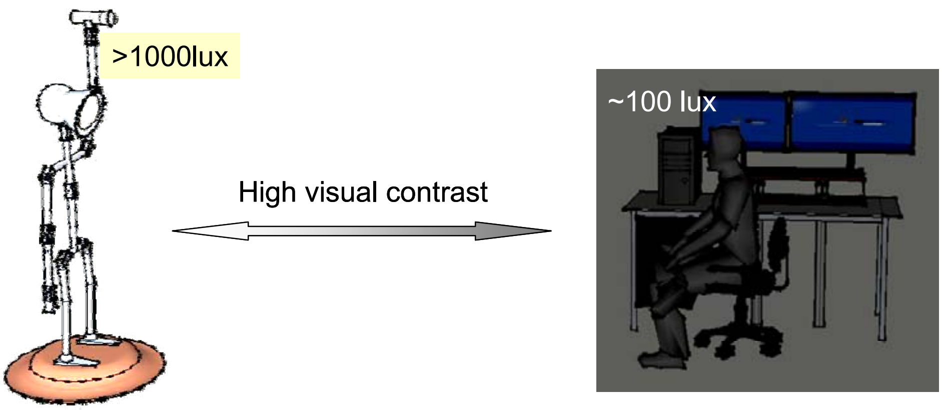
Blue Light hazard ratio is similar for all tested illumination conditions and varies between $3.7x10^{-4}$ and $4.0x10^{-4}$ W/lm: illuminance below ~ 2 klx could be considered Blue Light safe for 8h exposure. Measured illuminance at the foreseeable positions of news presenters and journalists does not exceed 1100 lx.

This assessment relates to the exposure of News presenters and journalists and does not include servicing or maintenance of luminaires.

TABLE H3 Desk D1: exposure during live broadcasting, Strand 650W Fresnel lights ON

Position	Ceiling lights only	looking at CP89	looking horizontally towards CP89	looking at PC screen	looking away from CP89
			Actinic UV		
Hazard level			<< 0.1 mW/m^2		
			MPE time >> 8h		
			UVA		
Hazard level, W/m^2	0.0048	0.037	0.02	0.0042	0.0021
			MPE time >> 8h		
hazard ratio, W/lm	4.3x10^{-5}	3.5x10^{-5}	4.6x10^{-5}	3.3x10^{-5}	2.9x10^{-5}
illuminance level to exceed ELV in 8h			>7 klx		
			Blue Light hazard		
Hazard level, W/m^2·sr	6.9	54.4	16.8	7.95	4.2
			MPE time > 8h		
hazard ratio, W/lm	4.9x10^{-4}	4.0x10^{-4}	3.1x10^{-4}	4.9x10^{-4}	4.6x10^{-4}
illuminance level to exceed ELV in 8h, lx	1600	1944	2566	1616	1696
Measured illuminance, lx	110	1057	431	129	72

Although the hazard level is well below applicable ELVs for journalists working at the desk D1 (D2 and D3 as well) and there is no foreseeable risk of overexposure, visual contrast, e.g. difference between illuminance levels *looking directly at lamp/computer screen* or *looking directly at lamp/ambient lighting*, is close to 10:1 and may cause visual discomfort, dazzling or compromise non-optical safety such as slips, trips, etc



H3 SHOEBOX

TABLE H4 Shoebox

Looking	at camera	right	left ~ 45°	left ~ 80°	at source, left ~ 80°	at source, left ~ 45°	straight on, at source	right, ~ 45°	up, worst case
Actinic UV									
Hazard level	<< 0.1 mW/m^2								
	MPE time >> 8h								
UVA									
Hazard level, W/m^2	0.009	0.0029	0.019	0.029	0.035	0.054	0.016	0.0042	0.04
	MPE time >> 8h								
hazard ratio, W/lm	2.9x10^{-5}	2.3x10^{-5}	3.1x10^{-5}	3.0x10^{-5}	3.0x10^{-5}	2.8x10^{-5}	2.2x10^{-5}	2.4x10^{-5}	3.5x10^{-5}
illuminance level to exceed ELV in 8h	> 10 klx								
Blue Light hazard									
Hazard level, W/m^2·sr	11.9	5.89	21.98	34.4	41.0	67.6	24.5	7.7	40.9
	MPE time > 8h								
hazard ratio, W/lm	2.9x10^{-4}	3.6 x10^{-4}	2.8 x10^{-4}	2.8 x10^{-4}	2.8 x10^{-4}	2.8 x10^{-4}	2.7 x10^{-4}	3.4 x10^{-4}	2.8x10^{-4}
illuminance level to exceed ELV in 8h	2663 lx	2206 lx	2818 lx	2861 lx	2823 lx	2941 lx	2986 lx	2311 lx	2784 lx
Measured illuminance	317 lx	128 lx	619 lx	985 lx	1158 lx	1988 lx	731 lx	178 lx	1137 lx

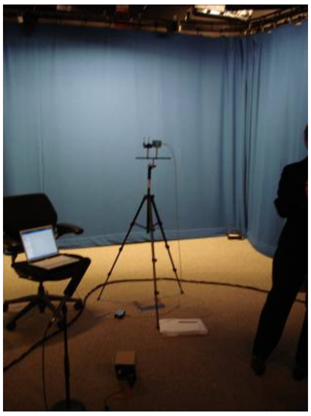
Exposure of News presenters and guests during broadcasting from Shoebox is not expected to present a risk of actinic UV, UVA or Blue Light hazards.

Actinic UV and UVA are substantially filtered out by the luminaires. UVA hazard ratio is similar for all tested exposure conditions and doesn't exceed 3.5x10^{-5} W/lm: 8h in the environment with the illuminance below 10 klx will not result in UV overexposure.

Blue Light hazard level is below 100 W/m^2·sr for all foreseeable exposure conditions.

Blue Light hazard ratio is similar for all tested exposure conditions and varies between 2.8x10^{-4} and 3.6x10^{-4} W/lm: illuminance below ~ 2.2 klx could be considered Blue Light safe for 8h exposure.

H4 SIGNING STUDIO



Accessible emission was measured at the eye level of Sign Language presenter.

Low illumination level (see photo on the left to compare brightness of laptop screen and ambient level).

Lighting by banks of fluorescent tubes without diffusers.

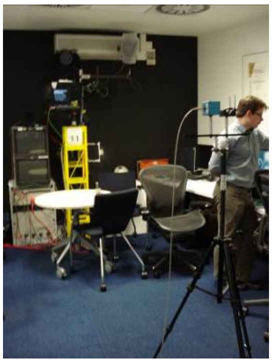
TABLE H5 Signing studio

Looking at:	camera	at luminaire	back, towards wall
	Actinic UV		
Hazard level		<< 0.1 mW/m^2	
	MPE time >> 8h		
	UVA		
Hazard level, W/m^2	0.00081	0.0018	0.0026
	MPE time >> 8h		
hazard ratio, W/lm	2.97x10^{-5}	6.2x10^{-5}	9.1x10^{-5}
illuminance level to exceed ELV in 8h		> 4 klx	
	Blue Light hazard		
Hazard level, W/m^2·sr	1.29	1.39	1.85
	MPE time >> 8h		
hazard ratio, W/lm	3.7x10^{-4}	3.8x10^{-4}	5.1x10^{-4}
illuminance level to exceed ELV in 8h, lx	2111	2081	1553
Measured illuminance, lx	27	29	29

Exposure of Sign Language presenter during broadcasting from Signing Studio is not expected to present a risk of actinic UV, UVA or Blue Light hazards.

Although the hazard level is well below applicable ELVs and there is no foreseeable risk of overexposure, significant difference between illuminance levels in Signing Studio and walkways of Studio A may cause non-optical safety concerns, such as slips, trips, etc.

H5 AROUND STUDIO A



Accessible emission was measured at eye level:

At desk under Philips CDM Coda

10 cm from LED strip on a wall

Looking up at ceiling fluorescent lighting near LED strip

Looking up at Philips CDM 3000K, same position near LED strip

First floor Gallery (looking at Lamp 105, see Fig.AY1)

TABLE H6 Around Sky News Studio A

position	Desk under Philips CDM Coda, looking horizontally	Desk under Philips CDM Coda, looking up	LED strip, looking directly at	Ceiling lighting, looking up	Philips CDM 3000K, looking up	Gallery, looking at Lamp 105	Gallery, same position
Actinic UV							
Hazard level	<< 0.1 mW/m^2						
MPE time >> 8h							
UVA							
Hazard level, W/m^2	0.0021	0.018	0	0.015	0.0093	0.017	0.016
MPE time >> 8h							
hazard ratio, W/lm	$7.0x10^{-5}$	$6.95x10^{-5}$	N/A	$5.0x10^{-5}$	$2.45x10^{-5}$	$7.3x10^{-5}$	$6.8x10^{-5}$
illuminance level to exceed ELV in 8h	>>4 klx						
Blue Light hazard							
Hazard level, W/m^2·sr	2.2	17.8	30.7	20.0	16.4	16.8	16.1
MPE time > 8h							
hazard ratio, W/lm	$5.95x10^{-4}$	$5.4x10^{-4}$	$1.2x10^{-3}$	$5.1x10^{-4}$	$3.4x10^{-4}$	$5.5x10^{-4}$	$5.4x10^{-4}$
illuminance level to exceed ELV in 8h, lx	1320	1460	650	1533	2304	1430	1445
Measured illuminance, lx	30	260	200	306	378	240	233

Exposure of personnel at the working areas of Sky News Studio A is not expected to present a risk of actinic UV, UVA or Blue Light hazards.

The LED luminaire has a higher Blue Light hazard ratio per lumen, compared with other luminaires.

H6 SUMMARY OF THE ASSESSMENT

Assessment of occupational exposures to optical radiation was assessed at Sky News Studio A under foreseeable worst case conditions at:

Newsdesk

Live News Studio 1

Shoebox

Signing Studio

Working areas around Studio A

Exposure of personnel at the working areas of Sky News Studio A is not expected to present a risk of actinic UV, UVA or Blue Light hazards.

Actinic UV and UVA are substantially filtered out by the luminaires.

UVA hazard ratio is similar for all tested exposure conditions:

(2-4)x10^{-5} for tungsten-halogen and (5-9)x10^{-5} for fluorescent lighting.

UVA hazard ratio doesn't exceed 9x10^{-5} W/lm – Studio A working environment with the illuminance below 4 klx could be considered UVA-safe for 8h exposure and doesn't require further assessment.

Blue Light hazard level is below 100 W/m^{2}·sr for all foreseeable exposure conditions. Blue Light hazard ratio is similar for all tested exposure conditions, with the exception of LED lighting, and varies between 2x10^{-4} and 6x10^{-4} W/lm: illuminance below ~ 2 klx could be considered Blue Light-safe for 8h exposure and doesn't require further assessment. For the majority of luminaires Blue Light hazard ratio is in the range of (3-4)x10^{-4} W/lm.

Although the hazard level in the assessed workplaces of Sky News Studio A is below applicable ELVs and there is no foreseeable risk of overexposure, significant difference between illuminance levels in some of the areas may cause non-optical safety concerns, such as slips, trips, etc.

This assessment relates to the foreseeable exposure of News presenters, journalists and supporting staff and does not include servicing or maintenance of luminaires.

Personal exposures during servicing or maintenance may require case-by-case detailed assessments.

APPENDIX I Case study: importance of UV filtering

UV emissions from daylight luminaires

Portable daylight luminaires are regularly used for TV programme making, at news locations and in filming for lighting presenters, guests and actors in daylight. Luminaires may be installed at a range of distances and used as stand alone lighting or in combination with other luminaires.

UVR is produced as a result of the operation of Hydragyrum Medium arc-length Iodide) (HMI lamps), in addition to visible light and infrared radiation. The UV components of the lamp output are not required for TV broadcasting or filming.

If UVR is not adequately filtered, by output optics or safety glass, accessible emission from such luminaires may present a significant risk of UVR overexposure to the skin and the eye. Filtering of hazardous UVR does not compromise the quality of illumination: human exposure to the visible light is essential for this application but UVR is an unintended by-product of lamp operation and should be avoided.

In existing luminaires, the risk of UVR overexposure could be further mitigated by a UV blocking filter that may be added as an additional element or as a thin film coating on the inner side of the existing safety glass. By optimising filter spectral characteristics, it is possible to essentially eliminate UVR hazards from the daylight luminaires.

The spectral irradiance from four daylight luminaires was measured to simulate 'worst case' UV exposure:

1 m from the luminaire,

Along central axis,

Luminaire operated at maximum setting,

With smallest beam diameter, where applicable.

The manufacturer's photometric data were used to evaluate the reduction of exposure level at the range of distances which these luminaires would be normally used.

All tested luminaires were equipped with original undamaged safety glass or Fresnel lens.

TABLE I1 Daylight luminaires

Luminaire	Lamp	Output optics
1	270W	Safety glass
2	400W	Fresnel lens
3	575W	Safety glass
4	575W	Fresnel lens

The UVR emission of the tested daylight luminaires measured at 1m is presented in Fig.I1. For comparison, this graph also shows solar irradiance measured at midday by HPA solar monitoring station in Chilton, Oxfordshire, on bright sunny day in June 2009.

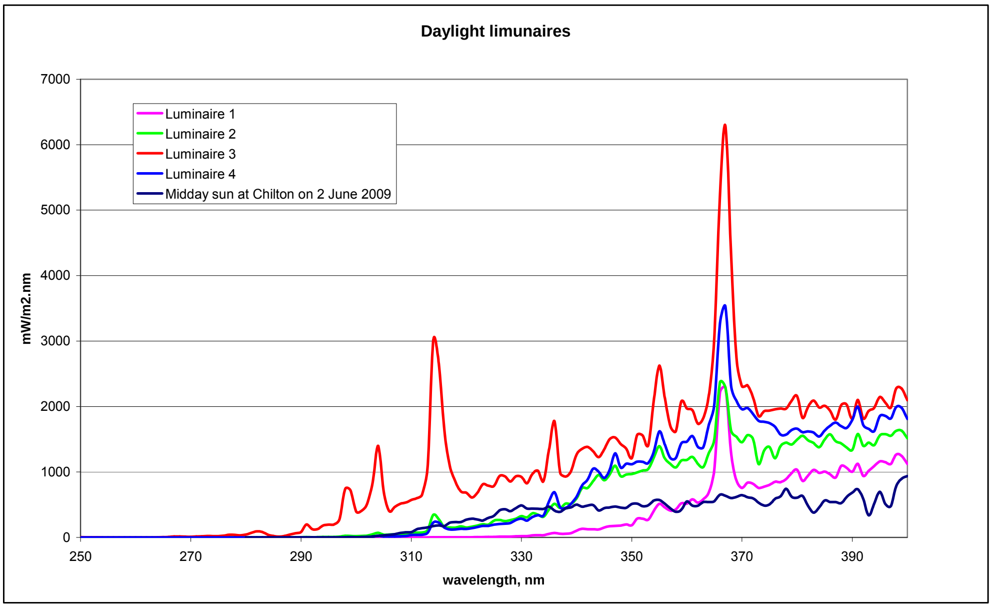


Figure I1. UVR accessible emission of daylight luminaires

Accessible UVR emission at 1 m from the tested luminaires is comparable to the midday summer sun; for Luminaire 4 – much higher. This difference is even more significant for biologically weighted irradiance, as illustrated in Fig.I2: *biological effectiveness of Luminaire 3 at 1m to cause adverse health effects is ~ 80 times higher than midday summer sun.*

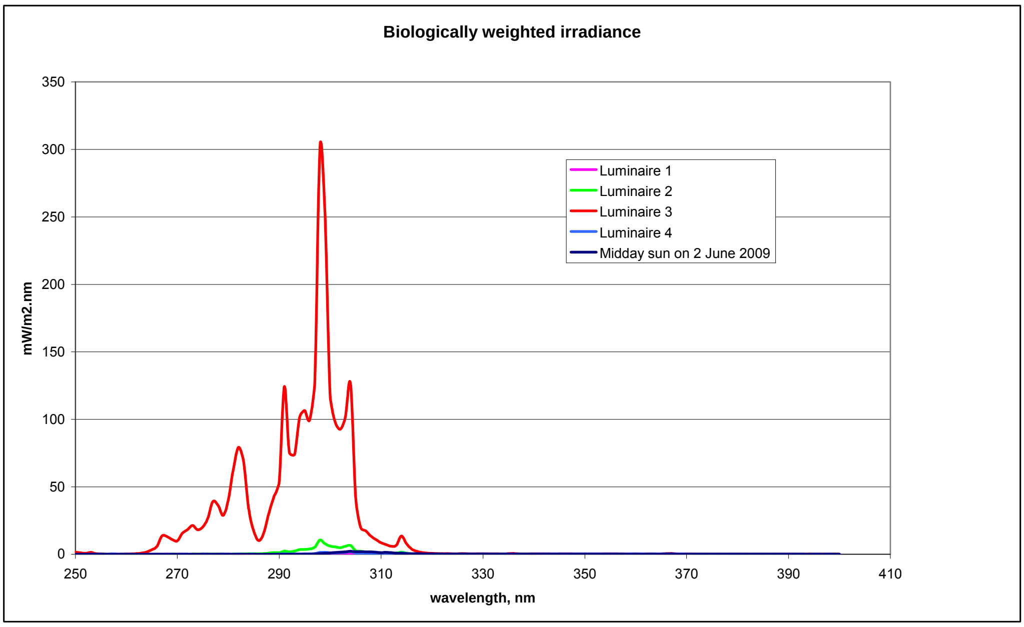


Figure I2. Weighted UVR accessible emission of daylight luminaires at 1m

The filter glass or attached optics (Fresnel lens) have substantially larger effect on the UVR assessable emission at the same distance than the wattage of the lamp. Thus, the UVR level of the Luminaire 3 is much higher than the UVR level of the Luminaire 4 (see Fig.I3), although these two luminaires employ identical MSR 575W lamps. Visible light performance of these luminaires is similar but actinic UVR hazard level of Luminaire 3 is approximately 86 times higher than that of Luminaire 4, due to inadequate UVR filtering by output optics.

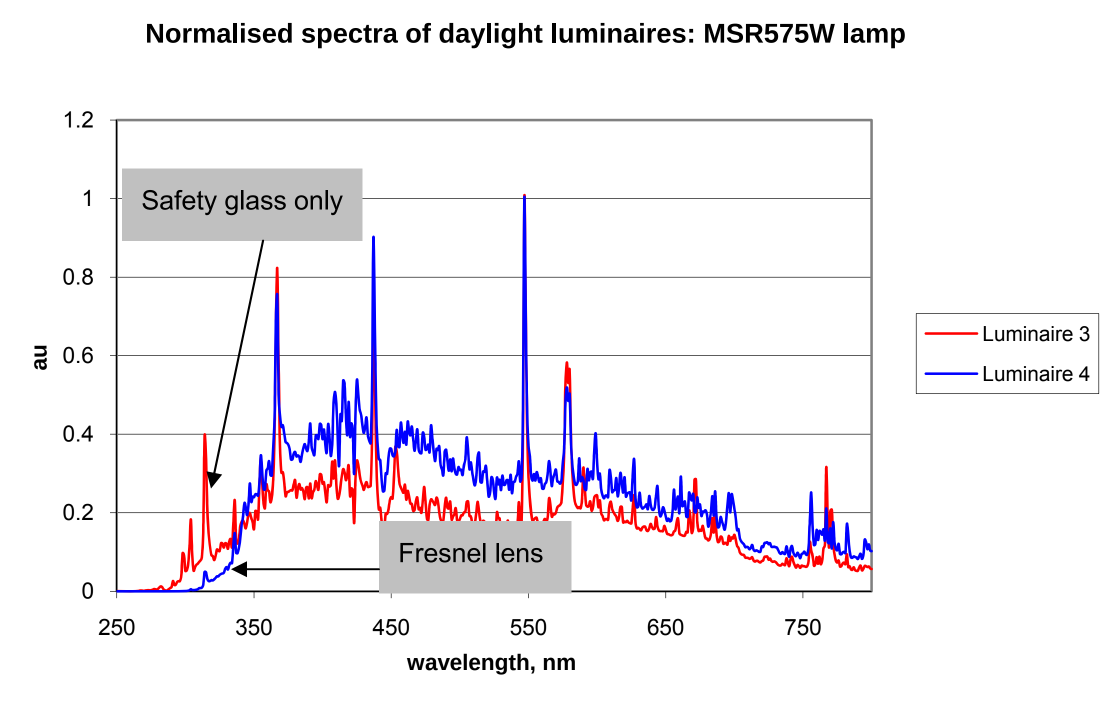


Figure I3. Emission spectra of daylight Luminaires 3 and 4 (equipped with identical 575W lamps).

The maximum permissible daily exposure times (***accumulative***) in the centre of the beam at 1 m from the luminaire are given in Table I2. This time is a total time of exposure within any 8h period, e.g. five 15 minutes sessions within 8 hours period result in 75 minutes accumulative exposure.

TABLE I2 Daily MPE time at 1 m

Luminaire	MPE time, actinic UV (skin + eye)	MPE time, UVA (eye only)
1	71 min	3.6 min
2	4.9 min	1.9 min
3	11 s	1.1 min
4	15.8 min	1.6 min

Because the safe operating distance (recommended by the manufacturer) for these luminaires is a minimum of 2 meters, the actinic UVR hazard level was calculated over increased distances. The daily MPE time will increase with the distance from the luminaire and moving away from the centre line of the beam. Table I3 illustrates the estimated reduction of the risk of skin and eye UVR overexposure with distance. However, multiple lighting sources at the same location may increase the hazard level, depending on position and the distance from presenter.

TABLE I3 Estimated increase of MPE time for actinic UV hazard for the skin and eye with distance

Luminaire	1m	2m	3m	5m	10m
1	71 min	>4.5h	>8h	>>8h	>>8h
2	4.9 min	19.6 min	44 min	2h	~6h
3	11 s	44 s	1.6 min	4.5 min	18 min
4	15.8 min	1h	2.5h	6.5h	>>8h

People in the centre of the beam (worst case scenario) of Luminaire 1 at realistic working distances of 3m and above are not expected to be at risk of skin overexposure; whereas accessible UVR emission from the Luminaire 3 may present a significant risk of UVR overexposure even at distances above 5m.

The risk of UVR overexposure may be reduced by:

Selecting the luminaire with the lowest UV emissions, suitable for the job;

Increasing the distance from the luminaire and moving away from the centre of the beam;

Limiting duration of exposure;

Use of skin care cosmetics and make-up products;

Filtering out harmful UVR emission.

Selecting the luminaire with the lowest UV emissions, suitable for the job

This option relates to procurement (a longer term control) and luminaire selection for each job. This is not often feasible and relies on comprehensive manufacturers' technical data, which is not always available in practice.

Increasing distance and/or limiting duration of exposure

As specific illumination levels may be required for the use of daylight luminaires, this option might compromise operational procedures and quality. This option also relies completely on human behaviour and, therefore, can't be considered reliable.

Use of skin care and cosmetics

Some skin care products, e.g. moisturisers and face creams, contain UV blocks to prevent skin photo-aging. These may reduce the UVR hazard level; use of make-up may add further skin protection (see Annex J for further information). However, this option can't be considered as a reliable control but could explain potential variations in any observed adverse effects.

Filtering out harmful UVR emission

UV radiation is produced by the lamps of daylight luminaires as a result of operation, in addition to visible light and infrared radiation (see Fig.I4), but is not required for their intended use.

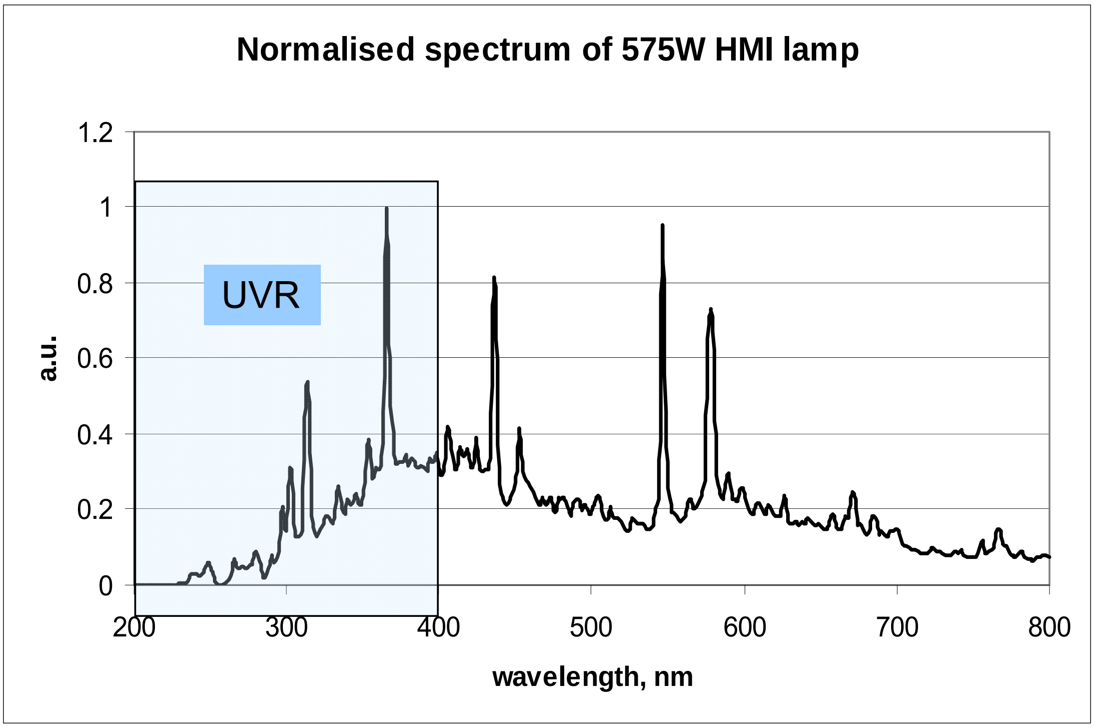


Figure I4. Emission spectrum of typical 575W HMI lamp without additional UV filtration*.

For the bare lamp in Fig.I4, without further UV filtration by the optics of luminaire, UV hazard ratios are very high; the illuminance levels before the applicable UV ELVs are exceeded and MPE times are extremely low: Table I4.

TABLE I4 Hazard values of lamp in Fig.I4

	Actinic UV	UVA	Blue Light hazard
Hazard ratio, W/lm	0.000125	0.0014	0.0012
illuminance level to exceed ELV in 8h, lx	8	244	858

Maximum permissible exposure time at different positions (based on the most restrictive Actinic UV hazard)

Illuminance, lx	500	1000	2000	10000
MPE time	8 min	4 min	2 min	24 s

UV blocking additives to the lamp envelope (UVC filtered lamps) greatly decrease UV accessible emission resulting in considerable reduction of Actinic UV and UVA hazard levels. Fig.I5 illustrates on an example of GE CSR 575 lamps, with (CSR 575/SE/HR/UV-C) and without (CSR 575/SE/HR) UV blocking additives. Actinic UV hazard level decreased by ~ 100 times for the same illuminance level; UVA – by a factor of 4. For the moderate illuminance environment (~1000 lux), a luminaire employing such a lamp would not present risk of overexposure, even without further UV filtration by the luminaire optics: see Table I5.

* Data are courtesy of GE

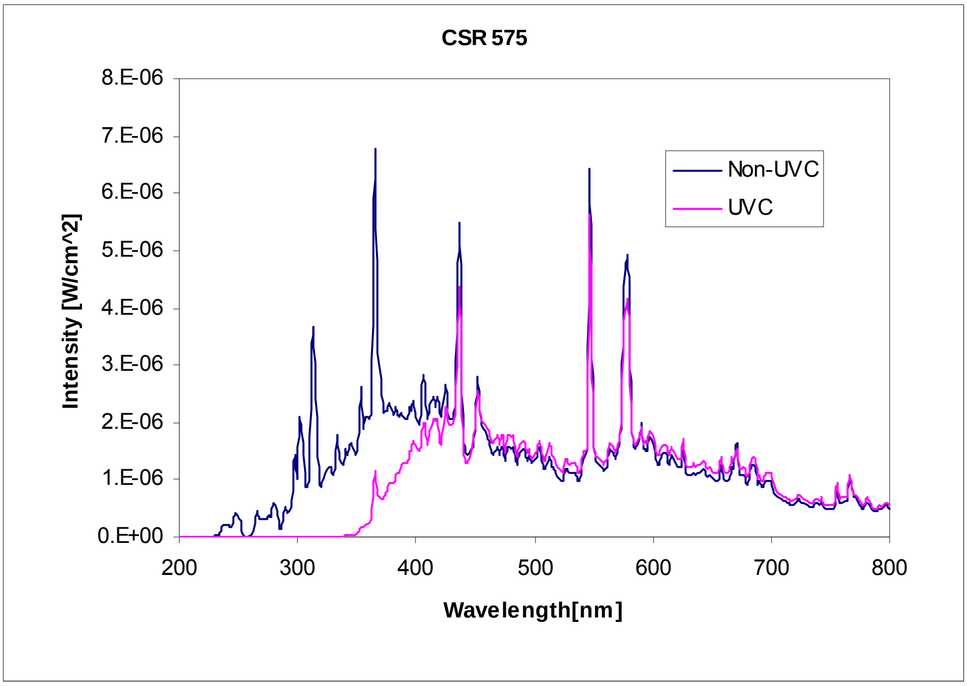


Figure I5. Spectral irradiance of GE CSR 575 W lamp, with and without UV-blocking additives*.

TABLE I5 Hazard values of lamp in Fig.I5

		Actinic UV	UVA	Blue Light hazard
Hazard ratio, W/lm	Without UV block	1.25×10^{-4}	1.42×10^{-3}	0.0012
	With UV block	1.18×10^{-6}	3.55×10^{-4}	0.0011
illuminance level to exceed ELV in 8h	Without UV block	8 lx	244 lx	858 lx
	With UV block	850 lx	977 lx	951 lx

Maximum permissible exposure time at different positions (based on the most restrictive Actinic UV hazard)					
Illuminance		500 lx	1000 lx	2000 lx	10000 lx
MPE time	Without UV block	8 min	4 min	2 min	24 s
	With UV block	>8h	~7h	3.5h	42 min

Filtering of hazardous UVR by the optics of a luminaire also may significantly mitigate the risk of overexposure, without compromising the quality of illumination: human exposure to the visible light is essential for this application but UVR is an unintended by-product and should be avoided.

Filter glass or attached optics have larger effects on the UVR accessible emission of the luminaires at the same distance than the wattage of the lamp. Bulky beam shaping optics (e.g. Fresnel lenses), as a rule, substantially attenuate UVR.

Luminaires are often fitted with safety glass to protect against explosion or disintegration of the lamp, as well as to filter UVR. Using a UVR blocking filter in addition to the safety

* Data are courtesy of GE

glass may considerably reduce accessible UVR emission. A UV blocking filter may be added as an additional element or as a thin film coating on the inner side of existing safety glass.

Fig.I6 illustrates how an application of an inexpensive acrylic UVR filter, even without optimisation of filter performance, results in an increase of MPE time for the actinic UVR hazard of the Luminaire 3, from 11 seconds to >>8h at the same distance of 1m: risk of UVR over-exposure is practically eliminated. Such a filter doesn't compromise the performance of the luminaire in the visible spectral range.

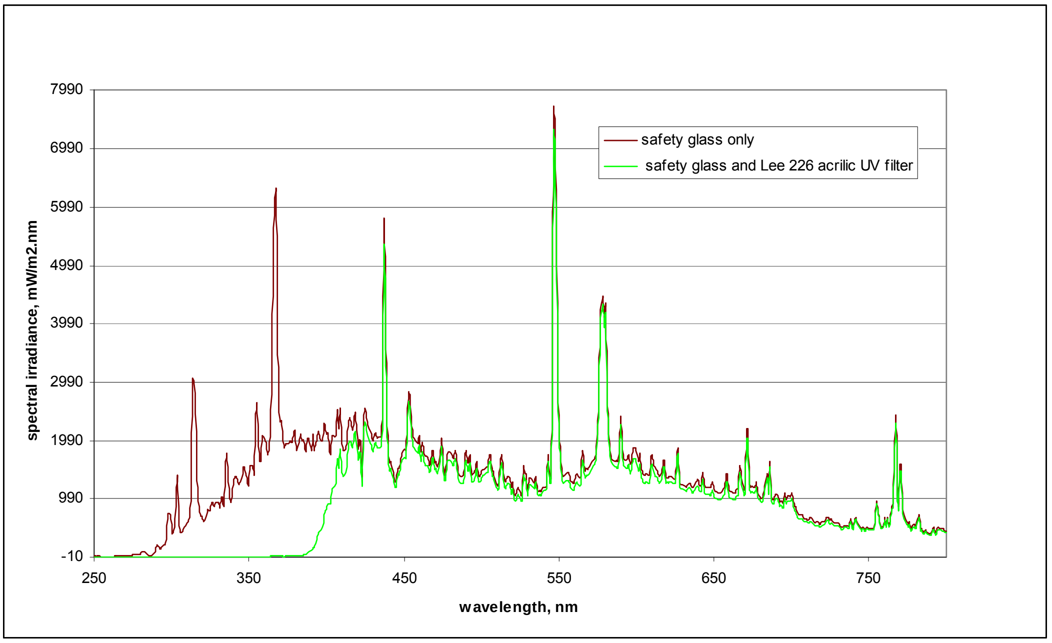


Figure I6. Attenuation of UVR accessible emission from Luminaire 3 at 1m by additional acrylic UV filter

If UVR is not adequately filtered, by UV blocking additives in the lamp envelope, output optics or safety glass of the luminaire, accessible emission may present a significant risk of UVR overexposure to the skin and the eye.

Unless speciality lamps with the UV blocking additives are used, UVR should be filtered out by the luminaires.

Filtering of hazardous UVR does not compromise the quality of illumination: human exposure to the visible light is essential in entertainment but UVR is often an unintended by-product of lamp operation and should be avoided

APPENDIX J UVR skin protection by make-up

Use of make-up could reduce the UV hazard level and provide additional protection for skin against the UVR. This is particularly important in filming where intentional exposure of the actors to the very intense light sources may be required for extended periods of time.

What?

Range of face, lips and body make-up used in films, TV and theatre; see Table J1

Who?

All samples were prepared by the Make-up Artist Heather Squire

How?

Make-up was coated on Transpore® by 3M film laminated in quartz slides. Different application techniques were compared for face foundation.

Spectral transmittance of make-up samples was measured immediately after application and then after 24h to evaluate potential changes in UV protection level.

Spectral transmittance was then used to calculate a Protection Factor (PF). Protection Factor is defined as a time-scale increase in exposure permitted for the skin protected by the make-up with respect to the unprotected skin. It is similar characteristic to SPF of sunscreens or UPF of fabrics and takes into account the different efficiency of UVR of different wavelengths on skin and the spectral attenuation of the make-up.

Protection Factor PF is calculated as follows:

$$PF = \frac{\sum_{200}^{400} E(\lambda)\, S(\lambda)\, \Delta\lambda}{\sum_{200}^{400} E(\lambda)\, S(\lambda)\, T(\lambda)\, \Delta\lambda}$$

where

$E(\lambda)$ – spectral irradiance of the source;

S(λ) - the UVR spectral weighting values [6];

T(λ) – the spectral transmittance at wavelength λ;

Δλ – the wavelength interval of the measurements.

Why not to use SPF?

Sunscreen SPF is a protection level for sun exposure; the emission spectra of entertainment lighting may be substantially different: see Fig.J2 for example.

Protection Factor PF of make-up samples was evaluated for daylight Luminaires 1-4 (see Annex I) and the sun for comparison.

TABLE J1 Make-up samples

Foundation	
Foundation Crème Compact CU1, Make Up International Kryolan Supercolor grease/paint: Beige F1 Orange 015	
Lipsticks	
Kryolan: LF102 mixed with LF104 Kryolan; LF101 mixed with LF111	
Liquid foundations	
Bobbi Brown Moisture Rich concealer/foundation; Beige 3 Clinique SuperBalanced; O6 Linen Rimmel Cool Matte 16th Mousse foundation; 100 Ivory	
Blushes	
Cream Blush by Make Up International: Rosy Dusty Pink Deep Red Bordeaux	

Powders

Max Factor Crème Puff powder Candle Glo

Elizabeth Arden transparent translucent powder 349

Whole body and face

Max Factor Colour Adapt Foundation 085 Caramel

Kryolan Aquacolor Green 509

Kryolan Aquacolor Orange 097

Kryolan Aquacolor Brown 228

RCMA Crème Porcelain

What did we find?

►There is no significant change in the protection level of the tested samples after 24h.

►Protection Factor (PF) of the same make-up may vary considerably for different luminaires: see Fig.J1. Some of the make-ups labelled with SPF (SPF15 for the Bobbi Brown foundation) for sun protection level; for daylight luminaires in filming or TV UV the protection level may be significantly different: PF of Bobbi Brown foundation for Luminaire 4 is almost half compared with SPF of the same sample.

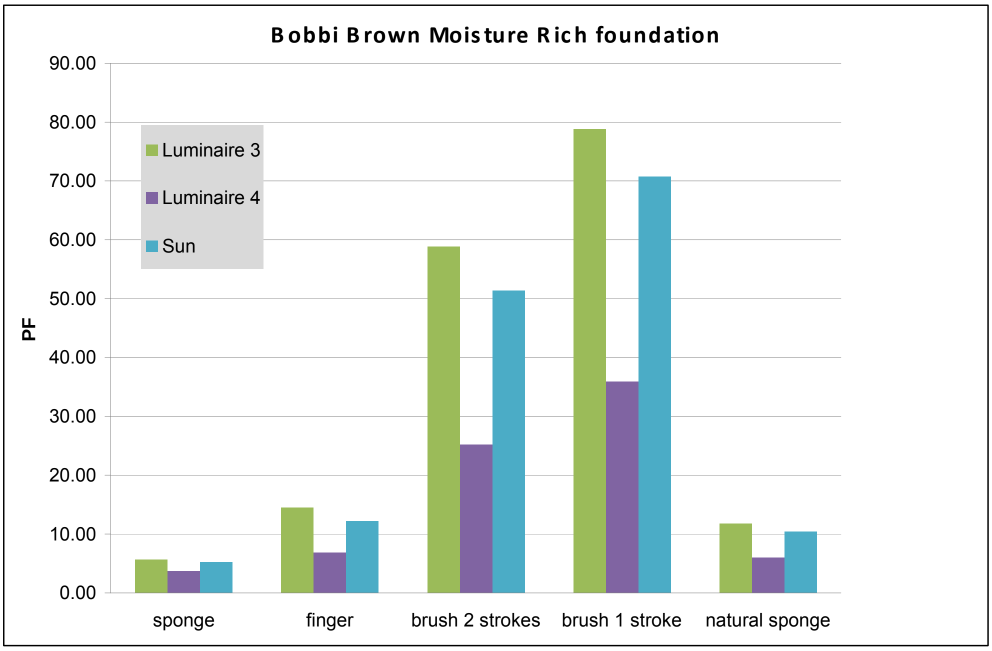


Figure J1. Protection Factor PF of Bobbi Brown Moisture Rich Foundation for Luminaires 3 and 4 (see Annex I); different application techniques are used

►Application technique has very strong effect on UV protection level: Protection Factor of Bobbi Brown foundation applied by sponge is ~ 20 times lower than FP of the same foundation applied by brush: see Fig.J1.

►Colour of some make-up might be a poor indicator of efficiency of UV protection. Thus, Protection Factors of Rosy and Dusty Pink blushes are higher than PF of blushes of more intense deeper colours Deep Red and Bordeaux: see Fig.J2. All blushes in this Figure are of the same type and make. Colour of the make up is a characteristic of spectral properties in visible light (how the eyes perceive), whereas Protection Factor characterises make-up in the (invisible to the eyes) UV spectral range.

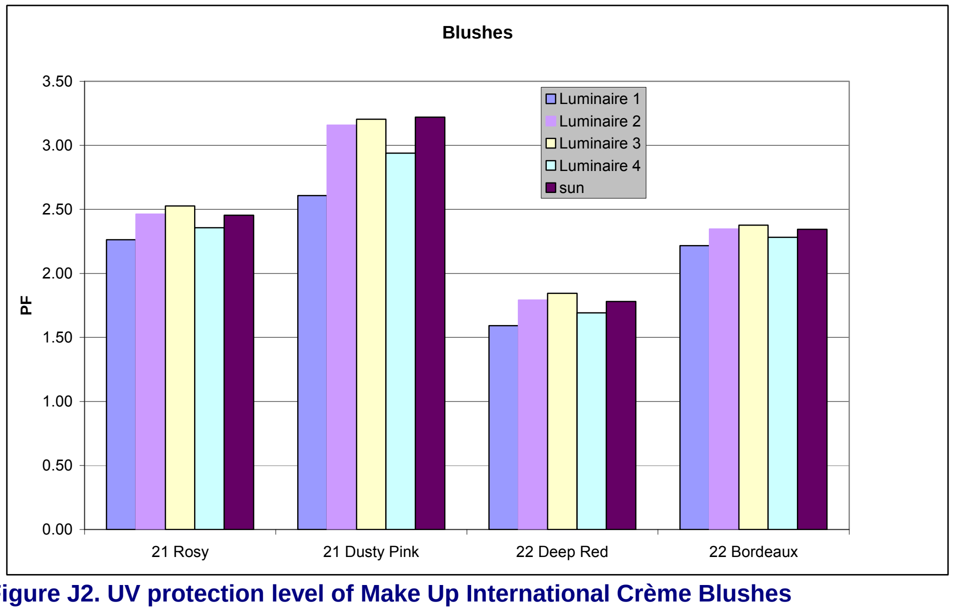


Figure J2. UV protection level of Make Up International Crème Blushes

►Protection level of liquid foundations applied by the same technique may vary considerably, as illustrated in the example of Fig.J3 for natural sponge.

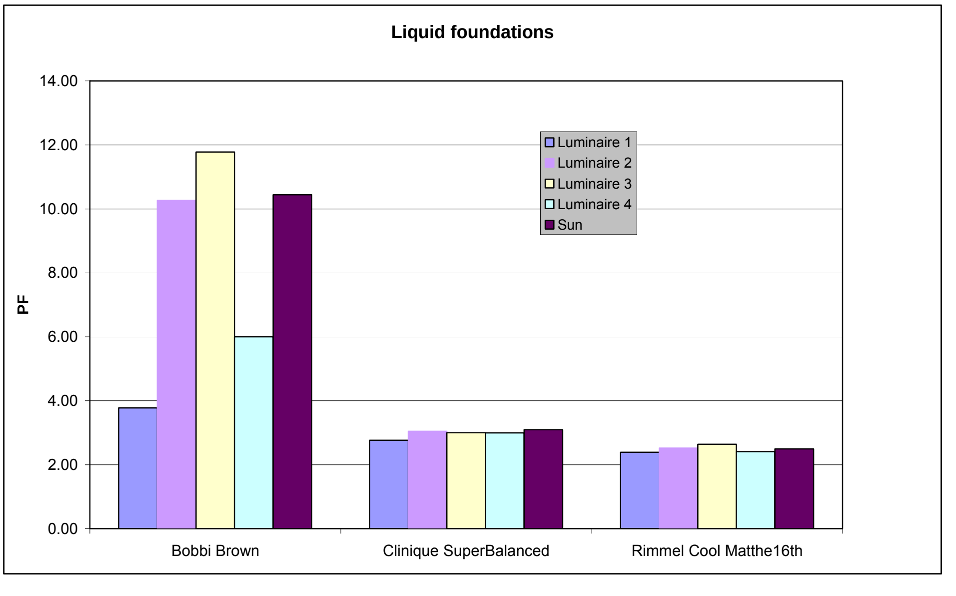


Figure J3. UV protection level of liquid foundations: all foundations are applied by natural sponge.

Clinique SuperBalanced and Rimmel Cool Matte 16th Mousse do not provide substantial additional UV protection for made-up skin (PF 2-3), whereas UV protection level of Bobbi Brown foundation may achieve PF10 for some of the analysed daylight luminaires.

►Tested powders do not add noticeable UV protection: see Fig.J4. Protection Factors of the tested powders do not exceed PF1.5.

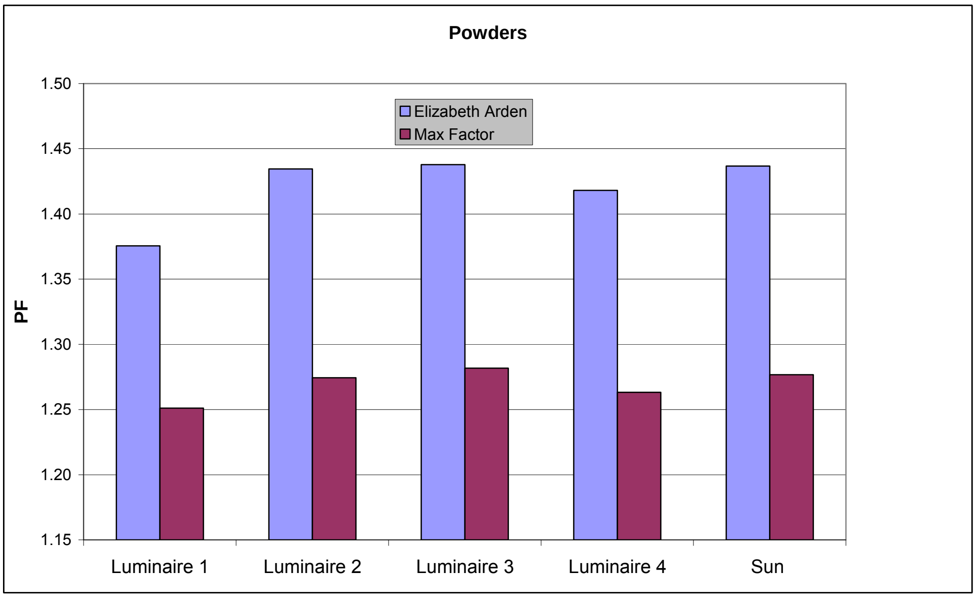


Figure J4. UV protection level of powders

►Tested Kryolan lipsticks provide ~ PF10 UV protection, similar for all assessed daylight luminaires: see Fig.J5.

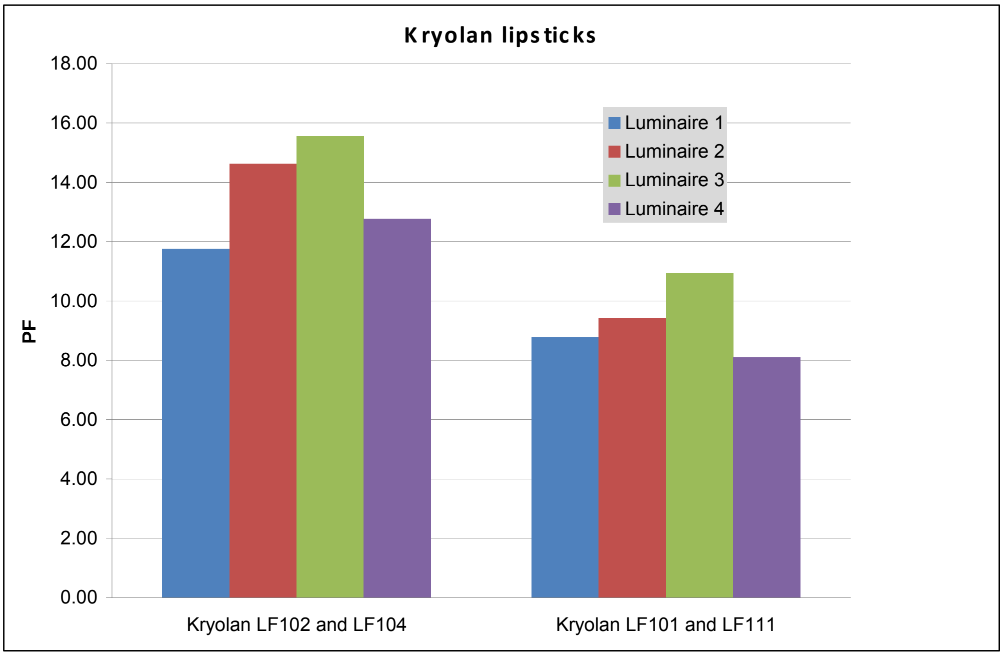


Figure J5. UV protection level of Kryolan lipsticks

►UV protection of whole body and face paint varies from ~ PF2 for Colour Adapt Caramel to PF180 of Kryolan Brown, with insignificant variations between assessed daylight lumunaires or sun: see Fig.J6.

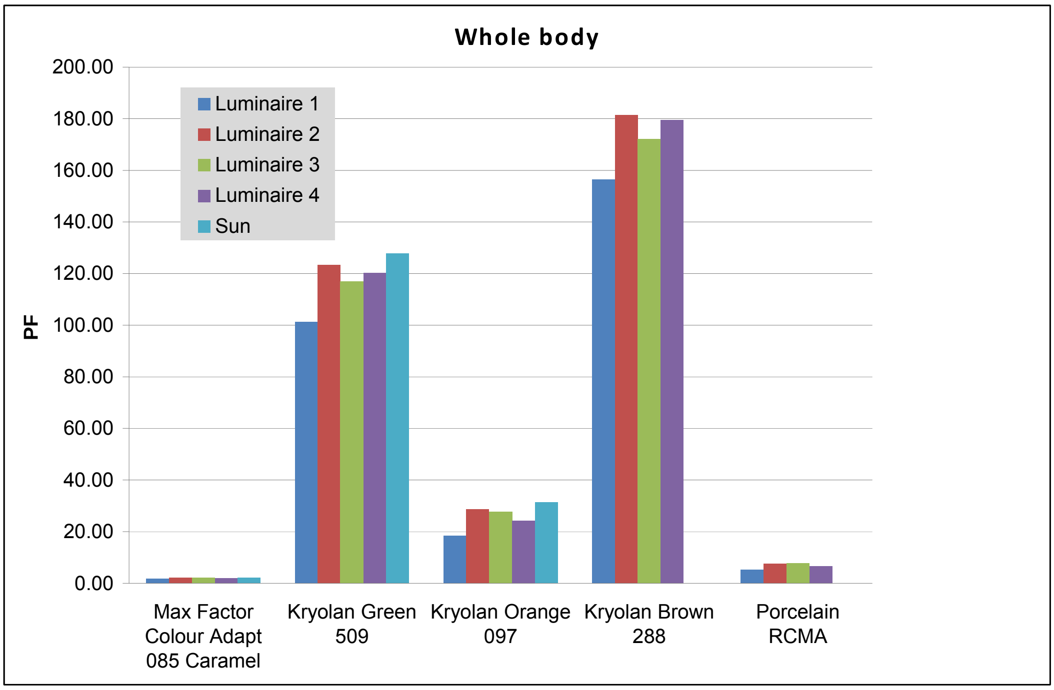


Figure J6. UV protection level of whole body and face paints

Make-up could provide additional protection to the skin against exposure to actinic UV. Protection level varies considerably for different luminaires and application techniques. Important practical implication of this finding is that make-up can not be considered as a reliable protection measure against skin exposure to actinic UV

APPENDIX K Optical radiation definitions, quantities and units

Accessible optical emission

Optical radiation to which the human eye or skin may be exposed for the conditions of reasonable foreseeable use.

Actinic UV hazard

Potential for photochemical injury to the eye and skin resulting from radiation exposure in the wavelength range 200 – 400 nm. The dose deposited is obtained by spectrally weighting the actual UV dose according to the actinic action spectrum values. Exposure limits are expressed as effective radiant exposure H_{eff} in joules per square metre [J m^{-2}]

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

and $H_{eff} = E_{eff} \cdot \Delta t$

where

E_{λ} is the spectral irradiance in $W \cdot m^{-2} \cdot nm^{-1}$,

$S_{UV}(\lambda)$ is the actinic ultraviolet hazard weighting function taking into account the wavelength dependence of the health effects of UV radiation on eye and skin [6],

$\Delta\lambda$ is the bandwidth in nm.

Angular subtense

Visual angle subtended by the apparent source at the eye of an observer or at the point of measurement.

Symbol: α

Unit: radian

Blue-Light hazard

Potential for a photochemically induced retinal injury resulting from radiation exposure in the wavelengths range 300 to 700 nm. This damage mechanism dominates over the thermal damage mechanism for times exceeding 10 seconds. Exposure Limits are expressed as effective radiance L_B in watts per square metre per steradian [W m^{-2} sr^{-1}]

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

where

L_λ is the spectral radiance in $W \cdot m^{-2} \cdot sr^{-1} \cdot nm^{-1}$,

B(λ) is the Blue Light hazard weighting function taking into account the wavelength dependence of the photochemical injury to the eye by blue light radiation [7],

$\Delta\lambda$ is the bandwidth in nm.

Exposure Limit

Maximum level of exposure to the eye or skin that is not expected to result in adverse biological effects.

Illuminance (E_v)

Quotient of the luminous flux $d\Phi_v$ incident on an element of the surface containing the point, by the area d*A* of that element

$$E_v = \frac{d\Phi_v}{dA}$$

Unit: lux

Irradiance

The radiant power incident per unit area upon a surface

$$E = \frac{d\Phi}{dA}$$

Unit: $W \cdot m^{-2}$

Lumen

SI unit of luminous flux. Luminous flux emitted in a unit solid angle (steradian) by a uniform point source having a luminous intensity of 1 candela, or equivalently, the luminous flux of a beam of monochromatic radiation whose frequency is 540×10^{12} hertz and whose radiant flux is 1/683 watt.

Luminance

Quantity defined by the formula

$$L_v = \frac{d\Phi_v}{dA \cdot \cos\theta \cdot d\Omega}$$

where

$d\Phi_v$ is the luminous flux transmitted by an elementary beam passing through the given point and propagating in the solid angle $d\Omega$ containing the given direction,

dA is the area of a section of that beam containing the given point,

θ is the angle between the normal to that section and the direction of the beam

Unit: $cd \cdot m^{-2}$

Lux

SI unit of illuminance. Illuminance produced on a surface of area 1 square metre by a luminous flux of 1 lumen uniformly distributed over that surface area.

Optical radiation

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

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

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

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

Radiance

The radiant flux or power output per unit solid angle per unit area

$$L = \frac{\mathrm{d}\Phi}{\mathrm{d}A \cdot \cos\theta \cdot \mathrm{d}\Omega}$$

where

$\mathrm{d}\Phi$ is the radiant power (flux) transmitted by an elementary beam passing through the given point and propagating in the solid angle $\mathrm{d}\Omega$ containing the given direction;

dA is the area of a section of that beam containing the given point;

θ is the angle between the normal to that section and the direction of the beam.

Unit: $W{\cdot}m^{-2}{\cdot}sr^{-1}$

Radiant energy

Time integral of the radiant power, Φ over a given duration, Δt

$$Q = \int_{\Delta t} \Phi \cdot \mathrm{d}t$$

SI Unit: J

Radiant exposure

The time integral of the irradiance; quotient of the radiant energy d*Q* incident on an element of the surface containing the point over the given duration, by the area d*A* of that element

$$H = \frac{dQ}{dA}$$

SI Unit: J·m^{-2}

Retinal Thermal hazard

Potential for an injury to the eye resulting from exposure to the optical radiation in the wavelength range 380 to 1400nm. Exposure limits are expressed as effective radiance L_R in watts per square metre per steradian [W m^{-2} sr^{-1}]

$$L_R = \sum_{380}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda$$

where

L_λ is the spectral radiance in W·m^{-2}·sr^{-1} ·nm^{-1},

$R(\lambda)$ is the Retinal Thermal hazard weighting function taking into account the wavelength dependence of the thermal injury to the eye by visible and IRA radiation [7],

$\Delta\lambda$ is the bandwidth in nm.

Spectral irradiance

Quotient of the radiant power $d\Phi(\lambda)$ in a wavelength interval $d\lambda$, incident on an element of a surface, by the area dA of that element and by the wavelength interval $d\lambda$

$$E_\lambda = \frac{d\Phi(\lambda)}{dA \cdot d\lambda}$$

SI Unit: W·m^{-2}·nm^{-1}

Spectral radiance

Ratio of the radiant power $d\Phi(\lambda)$ passing through that point and propagating within the solid angle $d\Omega$ in the given direction, to the product of the wavelength interval $d\lambda$ and the area of a section of that beam on a plane perpendicular to this direction

(cos θ dA) containing the given point and to the solid angle $d\Omega$

$$L_\lambda = \frac{d\Phi(\lambda)}{dA \cdot \cos\theta \cdot d\Omega \cdot d\lambda}$$

SI Unit: W·m^{-2}·sr^{-1}·nm^{-1}

Steradian

SI unit of solid angle. A solid angle that, having its vertex at the centre of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere

UVA hazard

Potential for photochemical injury to the eye resulting from radiation exposure in the wavelength range 315 – 400 nm. Exposure limits are expressed as radiant exposure H_{UVA} in joules per square metre [J m^{-2}]

$$E_{UVA} = \sum_{\lambda=315nm}^{\lambda=400nm} E_\lambda \cdot \Delta\lambda \quad \text{and} \quad H_{UVA} = E_{UVA} \cdot \Delta t$$

where

E_λ is the spectral irradiance in W·m^{-2} ·nm^{-1},

$\Delta\lambda$ is the bandwidth in nm.