 

# Evaluation and Characterization of Optical Radiation Sources in Medical Diagnosis and Treatment

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**Abstract**

Skin cancer, other related skin effects and vision impairment which can occur as result of exposure to optical radiations have been a source of major concern to the UK Government, European Union and the world at large. To combat this negative health related issues, professional organizations and scientist in various institutions and research centre have investigated the level of contribution of optical radiation to global health threats using different radiometry techniques. The goal has always been to drastically reduce occupational exposure to a barest minimum, but methods adopted by most researchers in the past are not adequate. This project work seeks to characterize the optical radiation sources by considering the geometry of the optical radiation source and the detector as well as the distance between them. The level of risk associated with the optical radiation sources at various distances was found to be increasing with increasing distances for extended sources and decreasing with increasing distances for point sources. The optical sources investigated appear to be safe in normal operation except for Bilurubin lamp and Dental curing lights. The control measures to reduce the risk associated with these sources were presented.

**Keywords:** optical radiation, spectroradiometer, radiation source, skin cancer, occupational exposure

## 1. Introduction

Electromagnetic radiation can be broadly divided into ionizing and non-ionizing radiation. Non-ionizing radiation is a form of radiation that does not carry enough energy to ionize atoms or molecules. It comprises of radio wave and optical radiation. The optical radiation can be further categorized into ultraviolet radiation (100-400nm), visible light (380 – 780nm), and Infrared radiation (780nm – 1mm). The ultraviolet may be classified into UVA (315 – 400nm), UVB (280 – 315nm) and UVC (100 – 280nm) while infrared as IRA (780 – 1400nm), IRB (1400 – 3000nm), and IRC (3000nm – 1mm) [7,5]. These classifications are arbitrary and differ from one discipline to the other depending on the environment for which the measurement is intended [2].

Sources of optical radiation are found naturally in the atmosphere (the Sun for example) and artificially in industrial, consumer, scientific and medical applications. The importance of these sources in the aforementioned fields of application cannot be overemphasized. However, risk analysis must be carefully carried out so that the health of persons involved is not compromised.

Due to its low energy, optical radiation can adversely affect only the human eye and the skin. The level of this effect depends on a number of parameters [9]. Most high intensity broadband sources produce IRC at very low levels compared with the emission at shorter wavelengths, which implies that risk assessment of IRC can be neglected [7].

This research aims to assess the potential hazard from occupational exposure to artificial broadband incoherent optical radiation sources which are used for medical applications. Initially the exposure is of less concern, but as a result of new inventions in the field of medical physics and optical technology, there are some reservations concerning the health of the medical personnel. This leads to the production of guidelines and directives to assist in protecting the health of the employee in his work place. These guidelines include International Commission on Non-ionizing Radiation Protection (ICNIRP), Physical Agents Directive (PAD), and American Conference of Governmental Industrial Hygienists (ACGIH) among others. The United Kingdom as a member of European Union is expected to comply with the PAD by 27$^{th}$ April, 2010 [5]. Assessment of optical radiation sources which are used for medical and other applications will greatly assist in complying with the directive.

The aim of this research is to carry out risk assessment of the optical radiation sources used in Hospitals under NHS

Greater Glasgow and Clyde in order to review the possible hazards and apply necessary control measures. This will improve the working condition to As Law as Reasonably Practicable (ALARP)

Safety is the most important aspect in every place of work and so it needs to be taken with all seriousness. Spending money on safety matters is indirectly saving a lot of money in the long-term. The PAD is not stringent giving room for member countries to come up with their directive according to their specific findings. The result of this research will greatly assist the staff in NHS GGC and the management in particular to implement the requirements of Physical Agents Directive.

## 2. MATERIALS

This work was carried out in Health Physics laboratory of Gartnavel Royal Hospital, Glasgow. Equipments used in the research include:

- USB 2000 spectroradiometer (Ocean Optics Inc.)
- Glen spectroradiometer (Glen Spectrad Ltd.)
- Thermocouple (with digital display)
- Optical radiation sources examined in this study include:
- Inspection lamps form Dermatology department Southern General Hospital
- Dental curing light from Glasgow Dental Hospital
- Infection control lamps from infection control department in Gartnavel Royal Hospital
- Medical illustration lamps from medical illustration department Gartnavel General Hospital
- Neonatal Phototherapy lamp from Children Hospital Yorkhill
- Endoscopy lamps form Bioengineering department Gartnavel General Hospital

### *2.1 Spectroradiometer*

This is an instrument used to measure irradiance of an optical source within a narrow bandwidth, centered at wavelength that is chosen by the operator. It comprises of input optics, a monochromator and a detector. For hand-held (USB) spectroradiometers all these components are combined together in one single box.

The optical radiation needs to be measured because of two reasons. Steady radiation exposure must be maintained on patients, animals or plants for a long period of time within a local laboratory. Secondly, the measurement of optical radiation will allow comparison of results from different laboratories. The first reason requires only precision, of which the spectroradiometer used has to be stable over a long time. For the second application, both precision and accuracy are important. This demands that apart from the stability of the spectroradiometer, the values displayed must be traceable to an accepted laboratory of standards (for example National Physical Laboratory) [3].

### *2.2 Principle of operation*

When optical radiation is collected at the input optics, it enters the monochromator through a slit located at the focal point of collimating mirror. The incident radiation is reflected as a beam from the mirror onto a dispersing element (prism or diffraction grating) which separates the optical radiation in to a spectrum. A second mirror (telescope mirror) receives the optical radiation from the dispersing element at a particular angle and focuses it on the exit slit of the monochromator. This final radiation will be detected at the exit slit using an appropriate detector (Figure 3.1). The detectors are normally Photo diodes, charged coupled devices (CCD) or Photomultiplier tubes (PM tube). The signal will be integrated depending on the collection time selected and transferred to a microcomputer for storage, analysis and display [4]. This is for USB 2000 spectroradiometer, but in the case of Glen spectroradiometer (Glen Spectrad Ltd.) which has double grating in its monochromator, it utilizes four collimating mirrors and two flat mirrors fixed at $45^{o}$. One facing the entrance slit and the other facing the exit slit. After the light has been dispersed by the first grating it will further be dispersed again by the second grating to further purify the beam and focus the selected wavelength out of the monochromator through the exit slit (Figure 2.1). Glen spectroradiometer has a focal length of 220mm, dynamic range of 280-804nm and resolution of 0.2nm at 500nm.

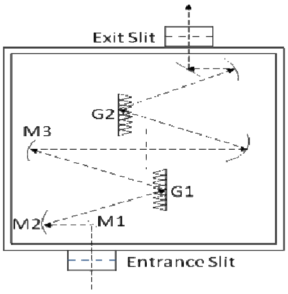


**Figure 2.1** Optical layout of Glen spectroradiometer

G1 and G2 are first and second diffraction gratings

M1 is the plane mirror at 45$^o$ which reflects the light to collimating mirror

M2 is collimating mirror reflecting light to the diffraction grating

M3 is collimating mirror collecting the dipersion beam from diffraction grating in to the second phase

The USB2000 spectroradiometer is a 2048 element linear CCD array with wavelength range of 200-1100nm and optical resolution of 0.3-10 nm FWHM. Its integration time varies from 1ms to 65s. It performs a single scan at about 1ms depending on the integration time, smoothing and averaging applied. Both the two equipments (Glen spectroradiometer and USB spectroradiometer) have a fiber optic cable and a diffuser block (figures 2.2 and 2.3). One end of the fiber optic is connected to the entrance of the optical bench while the other end is connected to the cosine corrector via SMA905 (in case of USB 2000).


**Figure 2.2** Complete spectrometer system consisting of the optics, detector, fibre-optic cable and cosine corrector.

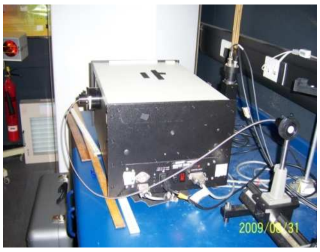

**Figure 2.3** Optical bench of Glen spectroradiometer consisting of detector, input optics and fibre-optic cable

The CC-3 cosine corrector is constructed form a PFTE diffusing material and is optimized for applications from 200-1100nm. Cosine correctors are spectroradiometric sampling optics, designed to collect optical radiation over 180°, thus eliminating optical interface problems associated with the light collection sampling geometry inherent to other sampling devices. The cosine corrector is screwed on to the end of the SMA905 terminated optical fiber.

## 3. METHODOLOGY

Data was collected by measuring the irradiance form the optical sources using the Glen spectroradiometer (Glen Spectrad Ltd.) which is calibrated against sources traceable to National Physical Laboratory (NPL) UK. The quantities measured include radiance and irradiance. These quantities are required to be measured over small wavelength intervals for assessment of hazard, as the effects vary with wavelength. Factors that can affect the quality of data include wavelength calibration, bandwidth, stray light radiation, polarization, angular dependence, linearity and calibration sources [3]. The use of a suitable input optics and double-grating monochromator will improve the wavelength discrimination. Since the stray light rejection is not efficient with single monochromators compared with double monochromators, inserting some filters at the input to block the stray light component reduces the stray light for single monochromator [10].

Another form of data was collected from published and unpublished literatures including books, journals, guidelines, directives and accident reports relating to hospital personnel. The Physical Agents Directive was the major source of secondary data.

### *3.1 Measurement Technique*

The value of irradiance was measured by placing the detector at various distances from the source. Spectral distributions were also determined for various angles of orientation of the detector from the optical axis of the source [6]. To be able to carry out a comprehensive risk assessment, two spectroradiometers were used; the calibration for one of which is traceable to NPL to allow data comparison for validation. The laboratory has all the potentials to carry out the measurement. Where an optical radiation source cannot be taken to the Health Physics laboratory for the purpose of measurement, the USB2000 spectroradiometer was used to carry out the measurement.

### *3.2 Risk Evaluation*

Following the guidelines set by the Physical Agents Directive as well as that of International Commission on Non-ionizing Radiation Protection, each source was analyzed and also characterized. The following were taken into consideration:

### *3.3 Source Identification*

The dimension of source, receiver and geometry between the source and receiver play a vital role in characterizing a radiation source; this only apply to sources emitting radiation in visible and infrared range [8]. Knowledge of the lamp type and the wavelengths of its emissions is also important (i.e. fluorescent, tungsten filament, LED etc.).

### *3.4 Exposure Distance*

Considering the mode of application of the source, the exposure distance was assessed and the distances at which the measurements were to be carried out decided. For some sources the best distance is about 0.01 m while for others it can reach up to 4 m. The use of a single distance for all sources will not allow a realistic evaluation of the potential hazards.

### *3.5 Exposure Limits*

The hazard evaluation is concerned with only non-coherent radiation that has a direct effect on eye and skin. The exposure limits are set for worst case (for example staring at an optical source for a period of 8 hours or more). The limits for occupational exposure to visible and infrared radiation incident on the eye or skin require the knowledge of irradiance and exposure periods. These exposure limits involve the use of hazard weighting functions (wavelength dependence of UV radiation $S(\lambda)$, wavelength dependence of blue light radiation $B(\lambda)$ and wavelength dependence of visible and infrared radiation $R(\lambda)$). All these are dimensionless quantities and were used to determine the effective values of radiance and irradiance, as well as exposure limit.

### *3.6 Geometric Factors*

For sources emitting infrared or visible light, the radiometric quantities and exposure limits will depend on the geometric factors. These factors were determined according to [1]. But for sources emitting only UVR, the geometric factors are immaterial as UVR does not penetrate further than the cornea and lens.

### *3.7 Preliminary Assessment*

In the assessment of white-light sources, a detailed spectral data is not required if the luminance does not exceed $10^4$ cd $m^{-2}$ or 1cd $cm^{-2}$. This is also applied to unfiltered incandescent, fluorescent or arc sources, which did not exceed retinal injury exposure limits and with luminance not more than $10^4$ cd $m^{-2}$ [8]. Therefore a preliminary test was performed on the sources that fall within this category, so as to determine whether it is necessary to fully investigate their potential to present hazard to the eye or skin. The meters that can give the value of luminance directly were used to make the preliminary assessment faster and easier.

### *3.8 Data*

Though the spectral range of optical sources covers from 100nm to 1mm, the wavelength range was chosen according to the nature of the source and the range at which it has non-zero emission. The range at which a source has zero emissions was ignored. The most important data is spectral irradiance or radiance that is weighted using the hazard functions.

### *3.9 Comparison*

The data obtained after necessary analysis and evaluation was compared to the exposure limit values (ELV'S) published by the European parliament and ICNIRP. Where the limits are exceeded, a more realistic assessment was carried out. If the hazard still exists control measures were suggested.

## 4. RESULTS AND DISCUSSION

Nine different optical radiation sources emitting optical radiation at different wavelengths were analysed. The guide provided by the International commission on Non-ionizing radiation protection as well as the Physical Agents Directive published by European parliament was used to analyse the data collected from the sources examined.

The total irradiance was obtained by integrating over the wavelengths of interest. The biologically effective irradiance was calculated by multiplying the irradiance value at each wavelength by a function (the biological weighting function).

### *4.1 Analyses of Optical Radiation Sources*

Having mentioned the procedures for risk assessment, each source was scanned with Glen spectrad as well as the portable (USB 2000) spectroradiometer where necessary. The results are presented in the following tables:-

### *4.2 UVR HAZARD*

*Dermatology Wood's Lamp*

The lamp is used for Irradiation of skin lesions with UV and the viewing of fluorescence, in dermatology departments and skin clinics. Diagnosis of various skin disorders can be achieved by employing fluorescence phenomenon. Application include determining the extent of infection, identifying areas of microbial sampling, evaluating treatment response, and differentiating between Erythrasma (which fluoresces coral-red under wood's light) and ringworm (which does not).

The wood's lamp is a low intensity ultraviolet lamp emitting UVA and some blue light, covered with a visible light absorbing glass filter commonly known as "black glass". Its dimensions are 7.1 cm by 4.6cm, and area 42.7 cm$^2$. The angular subtense α > 11 mrad, so radiance is used for assessment. Hazards to the eyes of operator and patient are expected from ultraviolet and blue light.

Glen Spectroradiometer measurements of spectral irradiance were performed at 10 cm, 30 cm and 60 cm. The results are displayed in table 4.1.

**Table 4.1** effective values of irradiance evaluated for UVA hazard from Dermatology wood's lamp

| Distance (cm) | $E_{eff}$ (W m$^{-2}$) | Exposure Limit (J m$^{-2}$) | Exposure time (h) |
|---|---|---|---|
| 10 | 6.3 x $10^{-4}$ | 30 | 13 |
| 30 | 1.2 x $10^{-4}$ | 30 | > 24 |
| 60 | 0.5 x $10^{-4}$ | 30 | > 24 |

*4.3 UVR and Blue Light Hazards*

*Infection Control Lamp (Portable)*

This is a portable lamp used as an educational aide by infection control departments. It uses UVA fluorescent lamp for the illumination and inspection of surfaces or hands to show poor hand washing techniques. The lamp tested was an HF4T5/BLB, 4 Watt lamp. Source dimensions were 11 cm x 1 cm, area 11 cm2. Angular subtense is 6 rads,

> 11 mrad, so radiance is used for the assessment. Ultraviolet and blue light hazards may only affect the eyes of operator and patient.

Spectral irradiance measurement was taken using the Glen Spectroradiometer at 10 cm source to detector distance.

Exposure to the direct beam from the lamp at 10cm will not cause any harm to the eyes or skin (table 3.2). Exposure limits cannot be exceeded by this type of lamp. It is used for illumination of the skin for the examination of fluorescence. Such lamp would not normally be observed directly, although this might occur for short periods of time. The irradiance/radiance is below the level at which there is any risk from UV or blue light exposure.

Since the source is not used with the operator looking directly at the lamp, the likelihood of an exposure exceeding the limit is RARE and the potential consequences from a single exposure to the blue light hazard are NEGLIGIBLE .Therefore overall the risk is LOW.

*Infection Control Lamp (Fixed)*

This is a UVA fluorescent lamp used for the identification of fluorescence associated with bacterial invasion on hands. The lamp is located in infection control departments of Hospitals and clinics. Lamp tested was an FL15T8BLB, 15 Watt, with dimensions 41.2 cm x 2.5 cm, area 103 cm$^2$.

The angular subtense is 21.85 rad, i.e. > 11 mrad, so radiance is used for assessment of blue light hazard. The hazards are from ultraviolet and blue light exposure to the eyes and skin of the operator and patient.

Glen Spectroradiometer measurements of spectral irradiance were taken at 10cm, and reflection was measured at 40cm from above the lamp cover to check for leakage.

Maximum exposure times were calculated based on UV and blue light exposure limits. Exposure to direct beam of this lamp must be limited to times indicated at the distances quoted in table 4.2. Exposure limits from UVR may be exceeded and therefore exposure of skin at distance of 10cm must be limited to 2h.

**Table 4.2** Maximum exposure limits form infection control lamps

| Source | Pat Number | Distance (cm) | UV $E_{eff}$ (W $m^{-2}$) | UV Skin Exposure Limit (J $m^{-2}$) | Max UV exposure time (h) | $L_B$ (W $m^{-2}$ $sr^{-1}$) | Max exposure time (blue light) (h) |
|---|---|---|---|---|---|---|---|
| Potable | HF4T5/BLB | 10 | 1 x $10^{-4}$ | 30 | > 24 | 0.01 | > 24 |
| Fixed | FL15T8BLB | 10 | 0.004 | 30 | 2 | 0.016 | > 24 |
| | | 40(reflection) | 8 x $10^{-6}$ | 30 | > 24 | 0.001 | > 24 |

*4.4 Blue Light Hazard*

*Dental Curing Light*

These hand-held units produce a visible spectrum output and are used for curing dental resins applied when filling teeth. The setting crystal contained in the dental resin composite is sensitive to and is activated by this particular spectrum of light. Exposure times clinically are 20-40s, usually in four exposures of 10 seconds each. There should not be a need to operate these lamps when they are directed towards the eyes as they are used inside the mouth. The lamp is used in most of the dental departments and dental clinics.

The blue LED lamp with 5W power remains on for a period of 10 s and has a diameter of about 5 mm, angle of subtense at 10 cm < 11 mrad. Since the angle of subtense is less than 11mrad, assessment is based on the lamp irradiance. The hazard from the source is Blue light which can affect the eyes of operator and patient.

Glen Spectroradiometer measurements of spectral irradiance were made at 10 cm, 20cm and 25 cm. Maximum exposure times were determined based on exposure limits. Output depends on state of charge of the lamp and may vary by ≈ ± 10%. Exposure to direct beam from the lamp is indicated at the distances quoted in table 4.3. At a distance of 10 cm the exposure limit could be exceeded in 5 – 10 s. There is a potential risk for exposure at the start and completion of each treatment.

**Table 4.3** Effective irradiance values measured from output of dental curing light

| **Distance from source (cm)** | **Effective Irradiance (W $m^{-2}$)** | **Maximum exposure time $T_{max}$ (s)** |
|---|---|---|
| 10 | 13.5 | 7 |
| 20 | 3.3 | 30 |
| 25 | 2.1 | 48 |

There is also potential for exposure to reflected light during the treatments. The sources should only be used when in-situ inside the mouth and should never be directed towards the eyes of the patient, the operator or any assistant. Protective filters may be used. Exposure of the eyes is only likely to result from careless use of the light source. The likelihood of an exposure exceeding the limit is UNLIKELY. The potential consequences from a single exposure to the blue light hazard are MINOR and therefore overall the risk is MEDIUM

*Bilirubinaemia Lamp*

This lamp is used for the treatment of neonatal jaundice. The baby is placed in a cot or a purpose-built irradiation cot with lamp above the baby. When the canopy is not in use the device is attached to a height adjustable stand which is also mobile. The baby's eyes are covered with a bandage (or filters are used) during the treatment to avoid exposure to blue light. Treatment procedures vary; but majority is six hours exposure followed by two hours off. The serum blirubin level is assessed every 8-12 hours and this may last for up to 6 days depending on the severity of the condition [2]. Several lamps could be used over one cot. There could be 2 or 3 infants undergoing treatment in one room. The lamp is made from a small bank of blue fluorescent lamps, with cover to avoid direct exposure of eyes for operators. The unit tested was a Bilicompact BAM/PL9/52, power 140 W. The bank of lamps was 46 cm long and 17.5 cm wide. It contained 10 fluorescent lamps; each lamp was regarded as the source and measured 11.5 cm x 1 cm, area 11.5 $cm^2$. Angular subtense is < 11 mrad, so a value of $\omega = 0.01$sr was used for the assessment. Hazard will arise only from the blue light to eyes of operator and patient.

Glen Spectroradiometer measurements were made at 20 cm, 40 cm and 100 cm source to detector distance to obtain spectral irradiance. Maximum exposure times were calculated based on blue light exposure limits. Exposure to the direct beam from the lamp should be limited to times indicated at the distances quoted in table 4.4.

**Table 4.4** Maximum exposure times to Bilirubin lamp at various distances

| Distance (cm) | $L_B$ ($W\ m^{-2}\ sr^{-1}$) | Max exposure time (blue light) (min) |
|---|---|---|
| 40 | 1110 | 15 |
| 60 | 550 | 30 |
| 100 | 240 | 70 |

Staff members should not have unprotected exposure of the eyes to the source at a distance of 1 m for more than 1 hour per day. If staff members are caring for the infant, and come within 0.5 m, and will be below the level of the lamp, then they should switch off the lamp for the period of care. There should be little from exposure to reflected light during the treatments and the sources are not used with operator looking directly at the lamp.

The infants should wear appropriate eye protection during treatments or their eyes should be covered.

Staff should restrict periods spent within 1 m of cots for infants undergoing treatment for bilirubinaemia to one hour per day. Staff should also monitor infants and reposition protective eyewear if it slips out of place.

The likelihood of an exposure exceeding the limit is POSSIBLE, but if the necessary procedures are followed, the potential consequences from a single exposure to the blue light hazard are MINOR. Therefore overall the risk is MEDIUM.

For units with integral blue light sources, it is recommended to have at least one daylight lamp so that nursery personnel can detect bluish complexion due to lack of oxygen in the blood circulating through the skin. Because it emits no heat in the direction of the patient, the lamp can be placed on the canopy of incubator bed.

*4.5 Blue Light and Infrared Hazard*

*Endoscopy Lamp*

The lamp contained in a box is used with a fiber optic delivery system to illuminate internal organs for close detailed examination of inner parts of the body which includes Gullet, stomach, duodenum and large bowel. It can be inserted into the body through natural openings like anus and throat or through a small surgical incision made in the skin. The endoscope may be rigid or flexible fiber optic containing a light source and a video camera, depending on the application and the operator technique. In some cases the rigid endoscope is used which has an objective lens at one end and eye piece at the other end. The lamp would not normally be observed directly, although this could occur for short periods of time if an endoscope was withdrawn with the lamp still illuminated, or if the exposure switch was depressed accidentally, or during testing in the electronic workshop. It is the light reflected from tissue back through the endoscope which will be viewed by the Endoscopist.

The white xenon lamp, shone through the endoscope fiber optic system (OlympusCLV-S20 and other models), were tested with a rigid endoscope. Light was emitted from tip of borescope 1cm in diameter, area 0.9 $cm^2$. Emissions were also measured through the viewing eye-piece that has a diameter of 0.8 cm and an area 0.5$cm^2$. Angular subtense is > 11 mrad, so radiance is used for the assessment. The hazard associated with this light source is that of blue light and thermal to eyes of operator and patient. There is a small amount of UV, but this is well below any limit and can be ignored.

Glen Spectroradiometer measurements of spectral irradiance of the direct beam were made at 10 cm and 30 cm source to detector distance. Measurements for reflection at 38.7 cm (the length of the rigid endoscope) were also made through the endoscope eyepiece by placing a white paper in front of the objective lens to create a reflection. Maximum exposure times were based on blue light and thermal exposure limits.

From the results shown in table 3.5, there is only a risk from direct viewing of endoscope light. Exposure limits cannot be exceeded by this type of lamp in normal circumstances as the source is not used with operator looking directly at the lamp and the lamp is not normally operated outside the body. When they are tested, they are directed away from other individual. Thus caution should be emphasized to the operators and they should be reminded that the lamp should not be directed at others. The likelihood of an exposure exceeding the limit is RARE and the potential consequences from a single exposure to the blue light hazard are NEGLIGIBLE. Therefore overall the risk is LOW.

*Dermatology inspection lamp (DL-122 Ring Handheld magnifier)*

Spectral irradiance was obtained using the Glen Spectroradiometer taking measurements at 10 cm, 20 cm and 30 cm of broad spectral emissions between 420 and 700 nm. A reflection measurement was taken at a distance of 10cm from the lens while the lamp was fixed at 10cm from the reflector. White paper was placed at a distance of 10cm from the lamp to represent the skin reflection. Maximum allowable exposure times were calculated based on blue light, visible and infrared exposure limits. These lamps would not normally be observed directly, although this might occur for short periods of time when others are using the lamps. It is the light reflected from the skin that will be viewed by the Dermatologist under magnification.

There is a potential for exposure to reflected light during the treatments, but the irradiance level is much lower and should not provide any hazard.

Exposure limit at the distances quoted cannot be exceeded by this type of lamp as indicated in table 4.5.

**Table 4.5** Maximum exposure times for Blue light and Infrared from Endoscopy and Inspection lamps

| Source | Distance(cm) | $L_B$ (W $m^{-2}$ $Sr^{-1}$) | Max exposure time (blue light) | $L_R$ ($Wm^{-2}$ $sr^{-1}$) | Exposure Limit ($Wm^{-2}$ $Sr^{-1}$) |
|---|---|---|---|---|---|
| ESPRIT 500 | 20 | 230 | 1 | $10^4$ | 1.2 x $10^8$ |
| (CW) Lamp | 50 | 43 | 6 | $10^4$ | 3 x $10^8$ |
| | 100 | 11 | 24 | $10^4$ | 3 x$10^5$ |
| | Reflection mode | 4 | >24 | 1,500 | 1.3 x $10^5$ |
| Pulse Mode | 0.3 | 20 | 1 pulse / s | 200 | 6 x $10^5$ |
| Inspect. Lamp | 10 | 1.3 | >24 | 16 | 2.8 x $10^5$ |
| | 20 | 1.3 | >24 | 16 | 2.8 x $10^5$ |
| | 30 | 0.8 | >24 | 10 | 2.8 x $10^5$ |
| | Skin | 0.6 | >24 | 5 | 2.8 x $10^5$ |

## 5. CONCLUSION

Apart from continuous wave sources, pulsed source and flickers are also used in medical diagnosis and treatment. Ophthalmologists for example, used the combination of flicker and pulse to study photopic and scotopic vision functionality in the human eye. Physical Agents Directive has not given a clear guide on how to perform a risk assessment of these types of sources. It is thus recommended that the Health protection Agency and Health safety Executives should come up with a clear guide on the assessment of pulsed sources as well as flickers.

All the measurements in this study were taken with the detector facing the optical source directly. It will be important to also study the effect of radiation at different angles. This will give a more realistic approach, so that the level of hazard associated with a particular source will not be exaggerated.

Among the nine (9) sources of optical radiation assessed, Bilurubin lamp and Dental curing lights appeared to have more harmful effect. But if the suggested control measures are implemented, it is expected that personnel and patients who are exposed to these optical sources will be safe within the normal operation.

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