THE IMPACTS OF OPTICAL RADIATION IN THE ENVIRONMENT ON SKIN: HAZARDS, MEASUREMENT, REGULATION AND PROTECTION

A thesis submitted for the degree of Doctor of Engineering

by

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Abstract

From 2001 to 2005, work was conducted at the Photobiology Unit at Ninewells Hospital in Dundee to examine the optical radiation environment and its implications for normal and diseased skin. Artificial sources of radiation were considered within the contexts of the hazards posed, measurement of the hazards, regulation concerning exposure and sources, and protection of abnormal skin from adverse effects.

The hazards posed by both ultraviolet (UV) and visible polychromatic sources were examined for normal and abnormal (chronic actinic dermatitis and solar urticaria) skin in an effort to predict the responses to such radiation. With current methodologies it was shown that responses to polychromatic light cannot be forecast for normal and abnormal skin.

Those hazards posed by light sources in the commercial sector are also considered. The sunbeds available in Perthshire and Dundee were evaluated spectroradiometrically and appropriate weighting functions applied. A case of adverse effects due to inappropriate use of an UV source is also presented and the implications are discussed.

Two diode array spectroradiometers were evaluated for their potential as instruments to measure UV sources. It was shown that one instrument could be used to give measurements with acceptable errors. However, later work with a different instrument of the same series showed that there are manufacturing

issues to be resolved before these instruments are marketed for widespread use in dosimetry.

Regulations governing exposure to and use of sources are considered where appropriate. Licensing of commercial sunbed parlours is suggested in order to enforce Health and Safety guidelines and the British Standard for such appliances, create a baseline for minimum standards of care within the commercial sector and safeguard public health.

Lastly, it has been shown that skin sensitive to visible light can be protected with commercial makeup preparations.

Contents

Contents

List of Figures

Executive Summary

This thesis considers light encountered from artificial sources and its effects on the skin. Normal skin is sensitive to ultraviolet (UV) radiation and exhibits an inflammatory response when the threshold dose is exceeded. Longer term effects include ageing and carcinogenesis. Photosensitive (abnormal) skin exhibits acute responses including swelling, excessive itching, erythema and blistering when thresholds for reaction are exceeded. The tolerable limits of exposure for normal and abnormal skin differ greatly.

In order to quantify the risks from artificial light sources, their spectra must be accurately measured. Spectroradiometers are the conventional approach to these measurements but these bulky instruments are not suited to transportation and on-site measurements. Two diode array instruments were evaluated during the course of this research [1] and one of these instruments was found to be suitable for the measurement of UV. These instruments represent a powerful tool for health hazard assessment.

There is a central paradigm in photobiology that assumes that the effects of polychromatic light can be predicted by using an appropriate action spectrum [2]. This assumes that wavelengths of radiation are additive in a linear manner [3]. In clinical photodermatology the response of skin is characterised using narrow bands of radiation [4]. Although this is useful for diagnostic purposes, sources such as these are rarely encountered in the environment and therefore the applicability of these tests to everyday life is dubious.

In order to test the hypothesis of additivity the results of conventional diagnostic techniques (phototesting) were used to construct action spectra. Tests were performed with polychromatic light on normal and abnormal skin. The results may indicate that the hypothesis is refuted for normal and abnormal skin. This result also casts doubt on the management of photosensitive skin conditions by avoidance of the 'causal' wavelengths. Instead, commercial cosmetic preparations are suggested as photoprotective agents for photosensitive skin. A range of products were evaluated and some found to match or better the alternative creams for protection from visible

radiation [5]. These products are more aesthetically pleasing than existing options and are readily available, some relatively cheaply.

Assessment of the hazards of UV radiation in occupational and commercial settings is important for public health. Cosmetic sunbeds have been a contentious public health issue for some years. Of particular debate is the number of sessions that are safe to receive in one year. A diode array spectroradiometer was used to make spectral measurements of all the sunbeds in commercial and council premises in two local authority areas. The differences in the strength of the radiation emitted from modern sunbeds were found to be huge. However, the dose received depends on the length of the session. The actual doses that may be received has not been considered when guidelines for the use of sunbeds has been published [6]. The dose received during every possible session on every bed surveyed was calculated. The results indicate that if the conservative approach of the precautionary principle is applied, the current medical guidelines of 20 sessions a year are prudent and rational.

However, within a regulatory context it was found that the majority of the units surveyed do not fit into any criteria as given in the British Standard* covering these units. Modification of the standard should be undertaken otherwise the standard is farcical.

A case study is also presented where inappropriate use of an UV source in an hotel kitchen led to adverse reactions amongst the staff [7]. Measurement of the offending light source and assessment of its hazards against occupational exposure guidelines revealed that workers had been exceeding their 8-hour occupational exposure limit [8] in just 14 seconds. The fact that these limits are only guidelines probably prevents any liable action being taken by the affected individuals. However, the fault really rests with the manufacturers of the UV unit as more than one type of tube could be fitted which inevitably leads to cases such as this [9].

This research was conducted at the Photobiology Unit at Ninewells Hospital in Dundee. This is a national centre for research on light associated skin disorders [10]. It

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* (BS EN 60335-2-27: 1997, Safety of Household and similar electrical appliances, Part 2. Particular requirements, Section 2.27 Skin exposure to ultraviolet and infrared radiation)

has a well-recognised publication record in clinical and laboratory photodermatology research with excellent links with British industry, both for investigation of drug-induced photosensitivity and development of new light sources. This Unit is ideally situated for research into abnormal skin as photosensitivity is more prevalent at northern latitudes because of higher proportions of fair skinned individuals [11].

Contribution to Knowledge

- Diode array spectroradiometers (notably a Sola Scope SC-MP-A from 4D Controls, Redruth, UK) can be used to perform spectral UV measurements intended for dosimetry purposes. The errors associated with the use of these instruments are within acceptable limits. These instruments have the added advantage of providing spectral information that can then be used for hazard assessment and therefore provide added functionality when compared with the filtered radiometers traditionally used for such measurements.

- When results from phototesting are used to construct an action spectrum for normal skin, it does not appear to respond as expected to polychromatic (ultraviolet) radiation. This may indicate that the erythemal response is not additive in a linear manner or that there are significant errors in the accepted methodology of phototesting.

- Chronic actinic dermatitis and solar urticaria also do not appear to respond in a linearly additive manner to polychromatic (ultraviolet and visible) radiation.

- Some commercial makeup preparations can be used to protect individuals sensitive to visible light. The protection afforded by some products betters that offered by the current alternative (Dundee creams [5]) and may be considered more aesthetic.

- Sunbeds currently available in two local authority areas in Dundee are of greater output than previously measured [12].

- The spectral distribution and strength of most sunbeds in the commercial sector in Perthshire and Dundee are such that they do not fit into any category in the existing British Standard for such units.

- Considering the actual length of sunbed sessions available, and the dose subsequently received, current medical advice of no more than 20 sessions per year is consistent with the precautionary principle in that the total dose received would not exceed the recommended 15 kJm^{-2} erythemally weighted dose per year.

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Chapter 1

Introduction

1. Scope of the thesis

This thesis focuses on the exposure of skin to artificial optical radiation sources in our environment and the hazards posed by this radiation. In order to properly understand the potential harm that light can cause we must quantify the intensity of the radiation through measurement and then we can assess the hazards posed by sources and the need for protection and/or legislation to control exposure.

Research was conducted in the University of Dundee's Photobiology Unit at Ninewells Hospital in Dundee. This is a national centre for the referral of patients with photosensitive skin and world prominent centre for research into the effects of light on skin.

The link with skin cancer, effects on the immune system and biosphere are all well documented and huge amounts of money have been poured into researching these effects. Hence, this thesis focuses on the potential of artificial sources to elicit responses other than skin cancer, although the carcinogenic potential of sources are also evaluated. Normal and abnormal skin is considered throughout this thesis. Normal skin is at risk from overexposure to ultraviolet radiation (UVR) but photosensitive skin can also be at risk from visible light.

Current legislation and guidance regarding exposure to optical radiation is considered in context. Means of protection from light is also considered. By extension this work also applies to exposure to the sun.

This introduction discusses the optical radiation environment and the science underpinning the effects of light on skin. Conditions leading to abnormal photosensitivity are explained and light measurement techniques are considered. Finally the bodies involved in light safety are mentioned and the work covered in chapters 2 to 6 is stated to allow the reader to identify the scope of the work.

2. Optical radiation in our environment

Our environment features optical radiation from many sources. Visible light is the basis of life on this planet. Plants use visible light to photosynthesise - therefore it is the basis of each and every food chain. Visible radiation stimulates the photoreceptors in the retina, which is the basis of human vision. It is also fundamental to the human circadian rhythm, which controls many biochemical processes. UVR has an important role in the synthesis of vitamin D, which is required for the development of bone.

In addition to its intrinsic importance to life, radiation at both visible and UV wavelengths add to our quality of life through warming effects and visual stimulation. During the course of a day, eyes and skin are exposed to many UV and visible photons from natural and artificial sources. Unfortunately, these photons are potentially harmful.

We can split the sources of light into two groups - natural and artificial. Natural light comes from the sun. Artificial sources of radiation are numerous and used for a myriad of purposes.

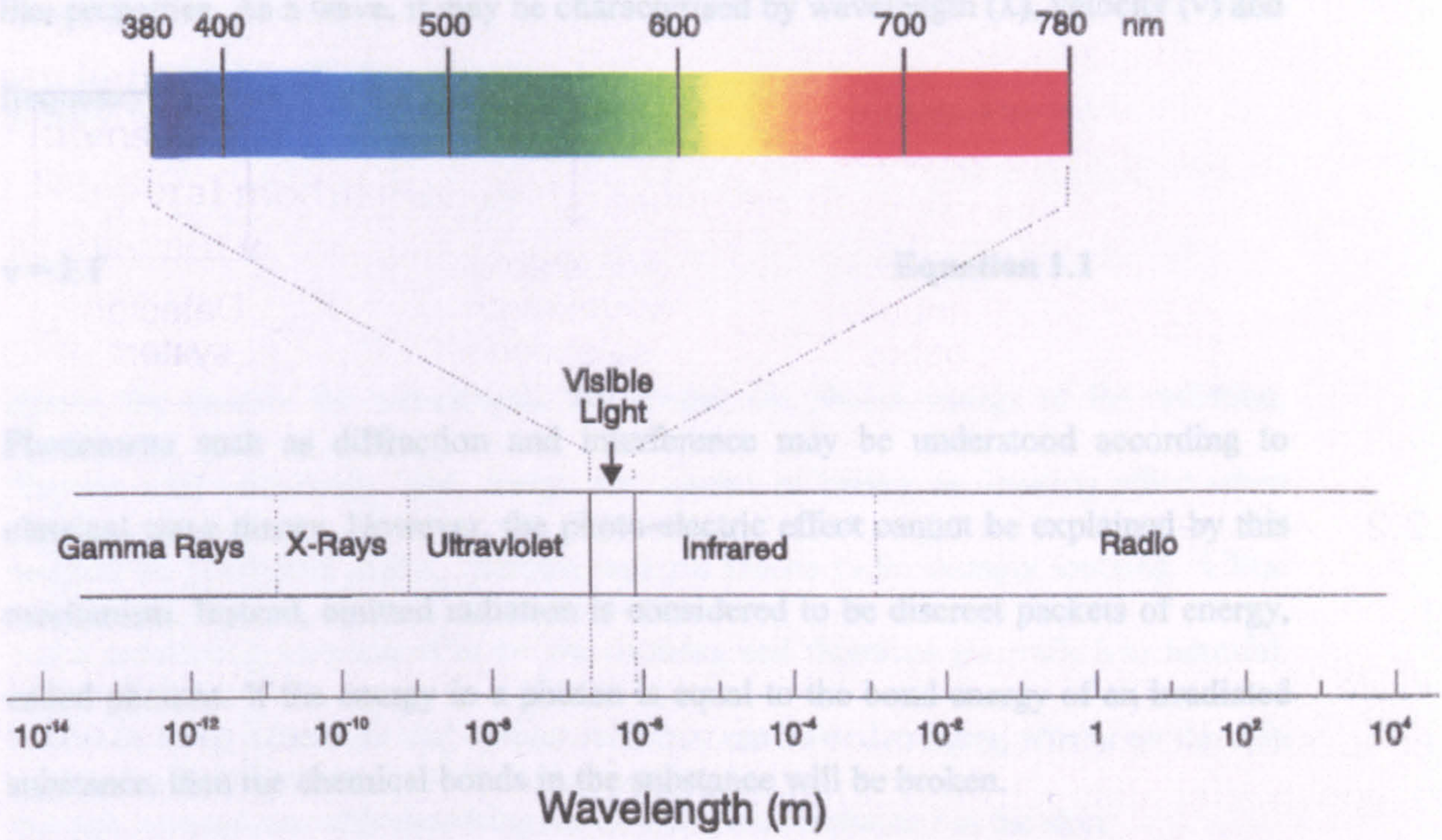
The primary use of artificial radiation is to help us see. The types of light source used for illumination are developing and changing as technology advances [1]. New light sources may expose the skin to different intensities and spectral distribution of radiation, the effects of which may not be known.

As well as helping us see, artificial light sources are used in equipment such as projectors and photocopiers. Operating theatres use strong overhead lights to assist surgeons. UV sources may also be encountered in our environment. Fly killers and welding equipment produce UVR and may represent occupational hazards. Sunbeds emit UVR and are used by choice to induce a suntan. There are also therapeutic uses of UVR. These are discussed later in this chapter.

3. Photophysics

Many parts of the electromagnetic spectrum (figure 1.1) are encountered in every day life. From gamma rays to radio waves, there are industrial, military and medical applications of the different regions of the spectrum. The term optical radiation includes visible and ultraviolet light.

Figure 1.1: The electromagnetic spectrum. Courtesy of Ray Lambe, NPL.



Ultraviolet radiation (UVR) is the part of the electromagnetic spectrum in the wavelength region from 100 nm to 400 nm. For convenience this radiation is divided into three different bands:

- UVC 100 to 280 nm
- UVB 280 to 315 nm
- UVA 315 to 400 nm*

Visible radiation is characterised by the visible spectrum of colours.

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* Note that the divisions UVA, B and C are arbitrary divisions and certain disciplines may use slightly different boundaries.

Electromagnetic radiation may be considered to possess both wave-like and particle-like properties. As a wave, it may be characterised by wavelength (λ), velocity (v) and frequency (f), related by the equation:

$$v = \lambda f \qquad \textbf{Equation 1.1}$$

Phenomena such as diffraction and interference may be understood according to classical wave theory. However, the photo-electric effect cannot be explained by this mechanism. Instead, emitted radiation is considered to be discreet packets of energy, called photons. If the energy in a photon is equal to the bond energy of an irradiated substance, then the chemical bonds in the substance will be broken.

The energy of each photon (E) is proportional to the frequency of the wave:

$$E = hf \qquad \textbf{Equation 1.2}$$

where h is Planck's constant

The wavelength of the radiation is proportional to the reciprocal of the frequency:

$$\lambda = \frac{c}{f} \qquad \textbf{Equation 1.3}$$

where c is the speed of light

Thus:

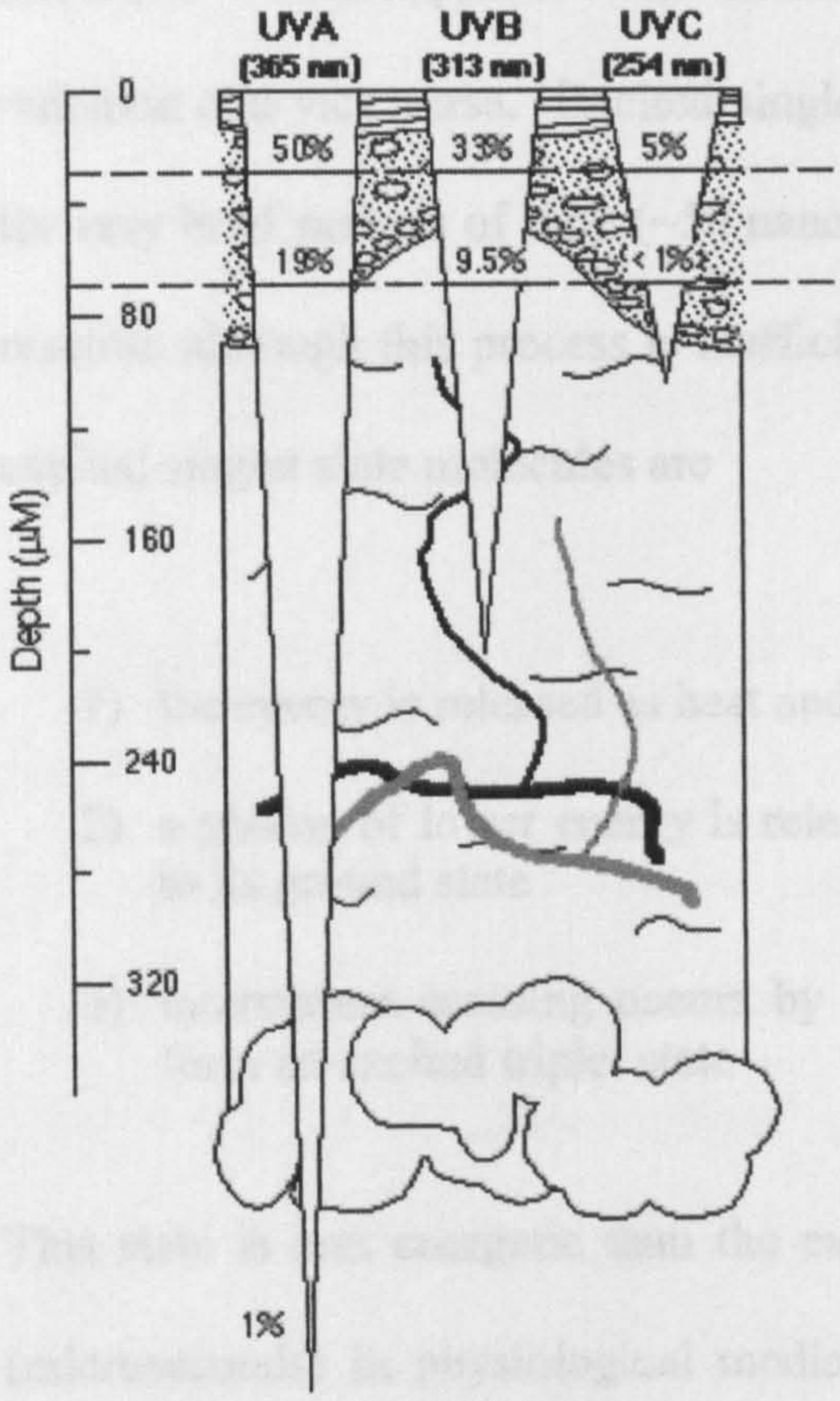
$$E \propto \frac{1}{\lambda}$$ **Equation 1.4**

Hence, the smaller the wavelength, the greater the photon energy of the radiation. Photons with sufficiently high energy are capable of having an ionising effect when incident on biological media. Gamma rays are known to be strongly ionising. Ultra-violet radiation is considered to be non-ionising and therefore generally less harmful. However, both ultraviolet and optical radiation can have damaging effects on the skin through interactions with absorbing molecules (chromophores) in the skin.

4. The interactions of light and skin [2]

The penetration of skin by photons of different energies is related to the wavelengths of those photons. Figure 1.2 shows the penetration depths of UVR. The longer the wavelength of the radiation the deeper it can penetrate into the skin. Hence, although UVC photons are most energetic they are able to penetrate the least and the effects of this radiation are confined to the outer layers of the skin.

Figure 1.2 The penetration depths of wavelengths of light into human skin. Reproduced from Drugge [3]



In order for a biological response to be seen in skin, photons must be absorbed by molecules in the skin. This is the Grotthus-Draper Law and is fundamental to the understanding of photochemistry and photobiology. Molecules in the skin that absorb radiation are known as chromophores and may be endogenous or exogenous. Exogenous chromophores are known as photosensitisers. A description of the chromophores in skin can be found in chapter 3.

When a photon is absorbed an energy conversion occurs and the chromophore becomes electronically excited or photoionisation occurs and an electron is removed

completely. The absorption of photons of different energies by molecules is dependent upon the energy gap between the ground state and singlet state of that molecule. Chromophores with small energy gaps will absorb long wavelength radiation and vice versa. Excited singlet state molecules are unstable and only exist for very brief periods of time (~50 nanoseconds). They may initiate a photochemical reaction although this process is inefficient. The three main processes that happen to excited singlet state molecules are

1) the energy is released as heat and the molecule returns to its ground state

2) a photon of lower energy is released as fluorescence and the molecule returns to its ground state

3) intersystem crossing occurs by changing the spin of one of the electrons to form an excited triplet state

This state is less energetic than the excited singlet state and can persist for longer (microseconds) in physiological media. This state decays by phosphorescence on release of a photon or via the singlet state by intersystem crossing. These are inefficient processes and the triplet state is more likely to release its energy and initiate a photochemical reaction.

5. Normal skin reactions

Normal skin exhibits an erythemal response when the minimum erythema dose (MED) is exceeded. This erythema, commonly known as sunburn, is an example of the inflammatory wounding response of the skin and is characterised by cutaneous inflammation- warmth, swelling and pain. The inflammatory response, onset 2-6 hours after exposure and at its maximum 15-24 hours after exposure, is the skin's first

reaction as the repair phase is delayed. Erythema fades in 72-120 hours and is usually followed by increased skin pigmentation and thickening of the epidermis [4]. Longer term effects of UVR [5] include increased skin fragility [6], ageing [7] and the development of skin cancers [8,9].

6. Abnormal reactions of skin to optical radiation

Although erythema can be painful it is only UVR that is responsible for erythema in normal skin. These wavelengths are easily avoided if precautions are taken such as avoiding the midday summer sun and wearing sunscreen. There are, however, individuals that suffer from abnormal reactions to optical radiation, including visible light, which has no adverse effects on normal skin. Abnormal responses include excessive sunburn, oedema, itch, pain, papules and blistering. Such individuals are known as photosensitive.

There are various conditions that can lead to photosensitivity. These are:

- Idiopathic photodermatoses
    - Chronic actinic dermatitis (CAD)
    - Polymorphic light eruption (PLE
    - Actinic prurigo (AP)
    - Solar urticaria (SU)
    - Hydroa vaccineforme (HV)
- Genophotodermatoses e.g. xeroderma pigmentosum
- Cutaneous porphyrias

- Erythrocytic
- Hepatic

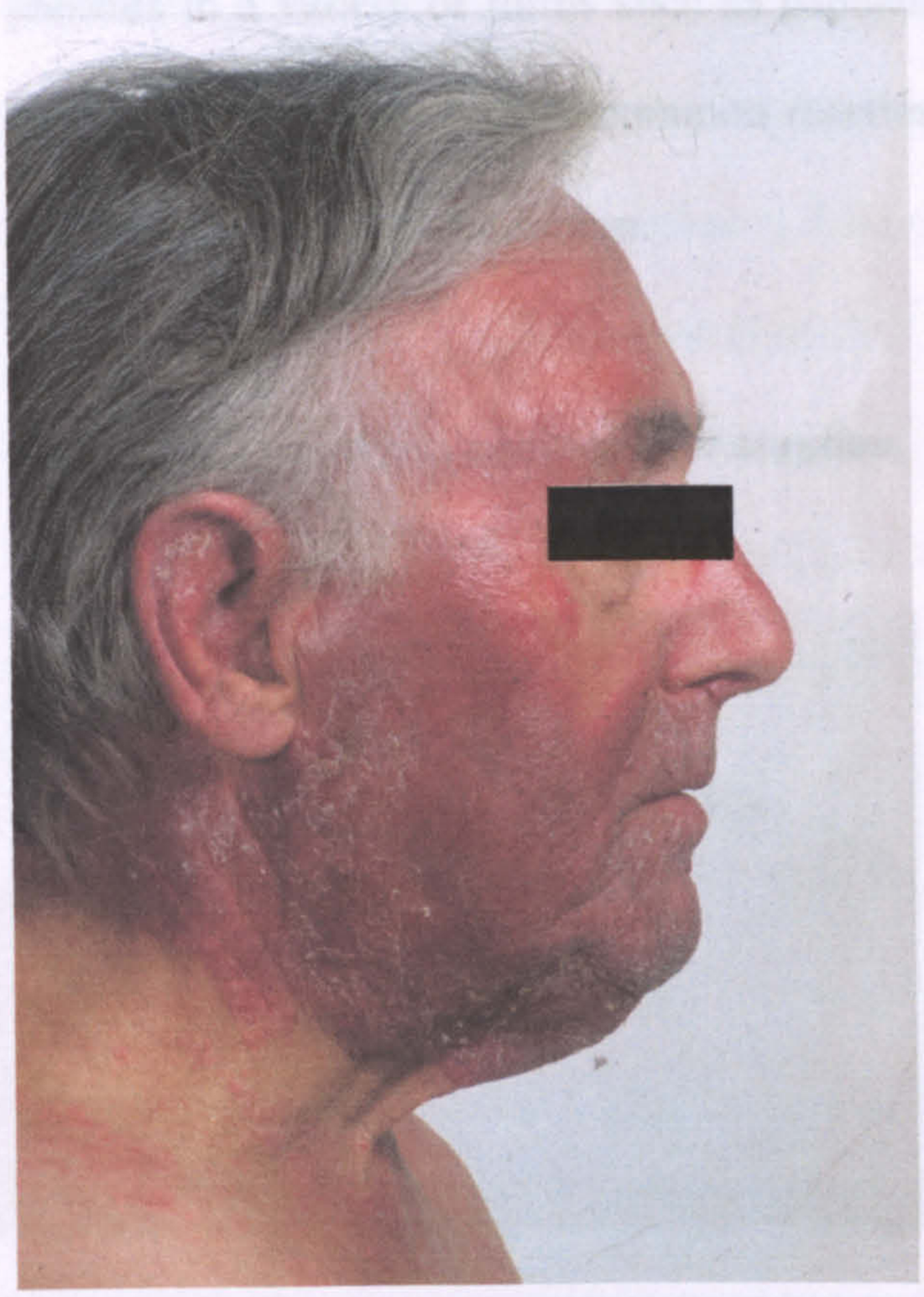
- Drug induced photosensitivity
- Photocontact dermatitis
- Photoaggravated dermatoses

CAD

The idiopathic photodermatoses are a diverse group of conditions. CAD is manifest as a persistent pruritic eczematous eruption with prominent lichenification mainly involving photoexposed sites (see figure 1.3) although the reaction can extend to covered sites. This condition usually affects elderly white males but has also been described in Japanese and individuals of skin types 4 and 5 [10]. This condition involves UVB and UVA in 95 % of patients and, in addition, visible radiation in 50 %. This condition can be disabling throughout the year. During acute episodes, patients are treated with topical steroids in specially adapted darkened rooms. Patients suffering from this condition often attempt suicide [11].

This condition can be associated with exposure to allergens (see chapter 3) and therefore patients must undergo patch testing to identify any causal agent. With careful management and allergen and or causal wavelength avoidance most patients condition will resolve [12].

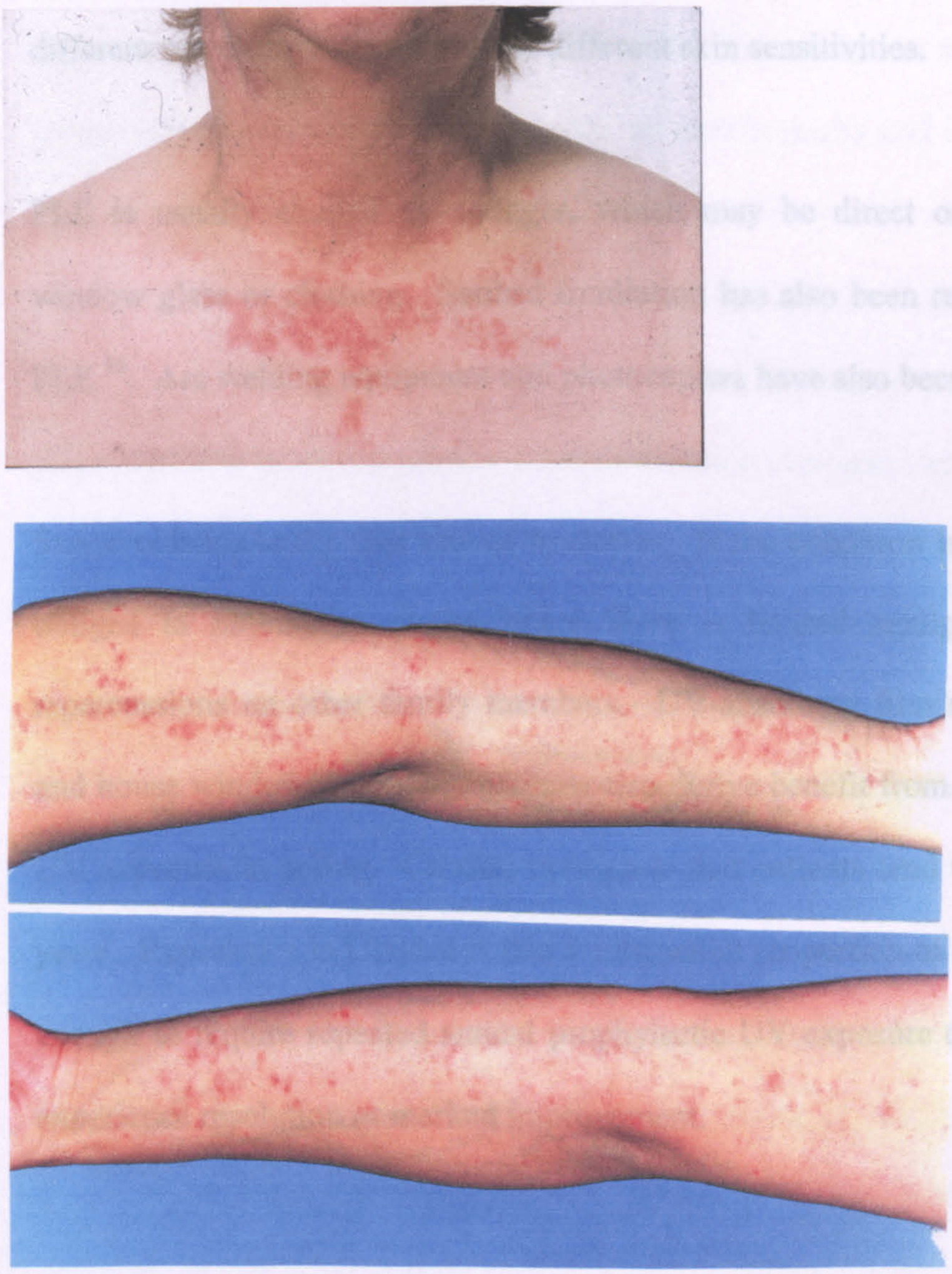
Figure 1.3 Chronic actinic dermatitis



PLE

Polymorphic light eruption (PLE) is a recurrent abnormal reaction to sunlight that presents in a variety of forms such as papules, vesicles, plaque, erythema, and itch. One author describes it as "a common reaction uncommonly recognized" [13]. Figure 1.4 shows a typical PLE reaction.

Figure 1.4 Typical polymorphic light eruption.



Often patients describe the onset of symptoms following 2 to 3 days' exposure on holiday. Thereafter, sunlight exposure as short as 10 minutes can produce an intensely itchy eruption. Symptoms usually resolve within a few days provided there is sunlight avoidance. PLE usually starts before the age of 30 and is diagnosed more frequently in females. It is more prevalent in northerly locations, such as Northern Europe, where the reported incidence is 12% compared to regions of high insolation, such as Australia (3% reported incidence) [14]. It is believed to be a delayed type hypersensitivity response to a photoallergen [15] but it is not known what causes PLE. Further, the reason for the geographical spread is uncertain. It may be related to the different wavelength distribution or different skin sensitivities.

PLE is usually elicited by sunlight, which may be direct or transmitted through window glass or clothing. Sunbed irradiation has also been reported as triggering a PLE [16]. Arc welding equipment and photocopiers have also been implicated [17,18,18].

Sun avoidance is the first line of treatment. If the condition is severe, the patient is obliged to holiday in places where there is limited sunlight. This has major repercussions on other family members. UV-absorbing film may be applied to car and house windows [19]. Many patients also derive benefit from a course of controlled UV exposure in spring. Clinical opinion is that patients tend to improve after some years. Experience in Dundee is that a substantial proportion of those with PLE severe enough to require repeated annual prophylactic UV exposure do, after several years, experience resolution or marked improvement.

AP

Actinic Prurigo (AP) is uncommon except in American Indians where it also shows a high familial tendency. AP patients have a perennial problem, with spring and summertime exacerbation. Exposed skin response to sunlight has two phases. First there is a delayed onset pruritic oedematous erythema. Second there is chronic background involvement with a widespread irritable skin eruption, termed prurigo, which develops within weeks. There may be secondary infection and pitted scars. All exposed sites, including face and hands, are usually involved. Approximately one third of patients exhibit normal sensitivity to wavelengths causing erythema but most show abnormal sensitivity to UVA and UVB. Treatment is sunlight avoidance and a course of desensitisation. Thalidomide, an oral hypnotic and immunosuppressive, is also effective.

SU

Solar urticaria is an uncommon photodermatosis, characterized by the appearance of pruritic wheals after sun exposure [20]. It affects more women than men [10] and may manifest at any age. The reaction may be triggered by direct radiation or through window glass and even through thin cotton clothing. Most patients are affected throughout the year [21]. Episodes may be accompanied by systemic symptoms such as headache, nausea, broncospasm, faintnesss [22] and loss of consciousness [23]. Wavelengths of up to 700 nm can be involved. In Dundee the probability of clinical resolution at 5 and 10 years after diagnosis was found to be 0.12 (95 % confidence interval) [21].

HV

Hydroa vaccineforme is a rare photodermatosis affecting an estimated 0.34 people per 100,000 [24]. It affects more males than females and is usually onset in the first decade of life. The skin is active during spring and autumn months. Exposed sites develop an itchy, stinging erythema with oedema within hours of exposure. Papules and vesicles follow and the vesicles may be fluid filled and at risk of secondary infection [23]. These painful lesions heal with the formation of characteristic depressed pock-like scars.

Genophotodermatoses

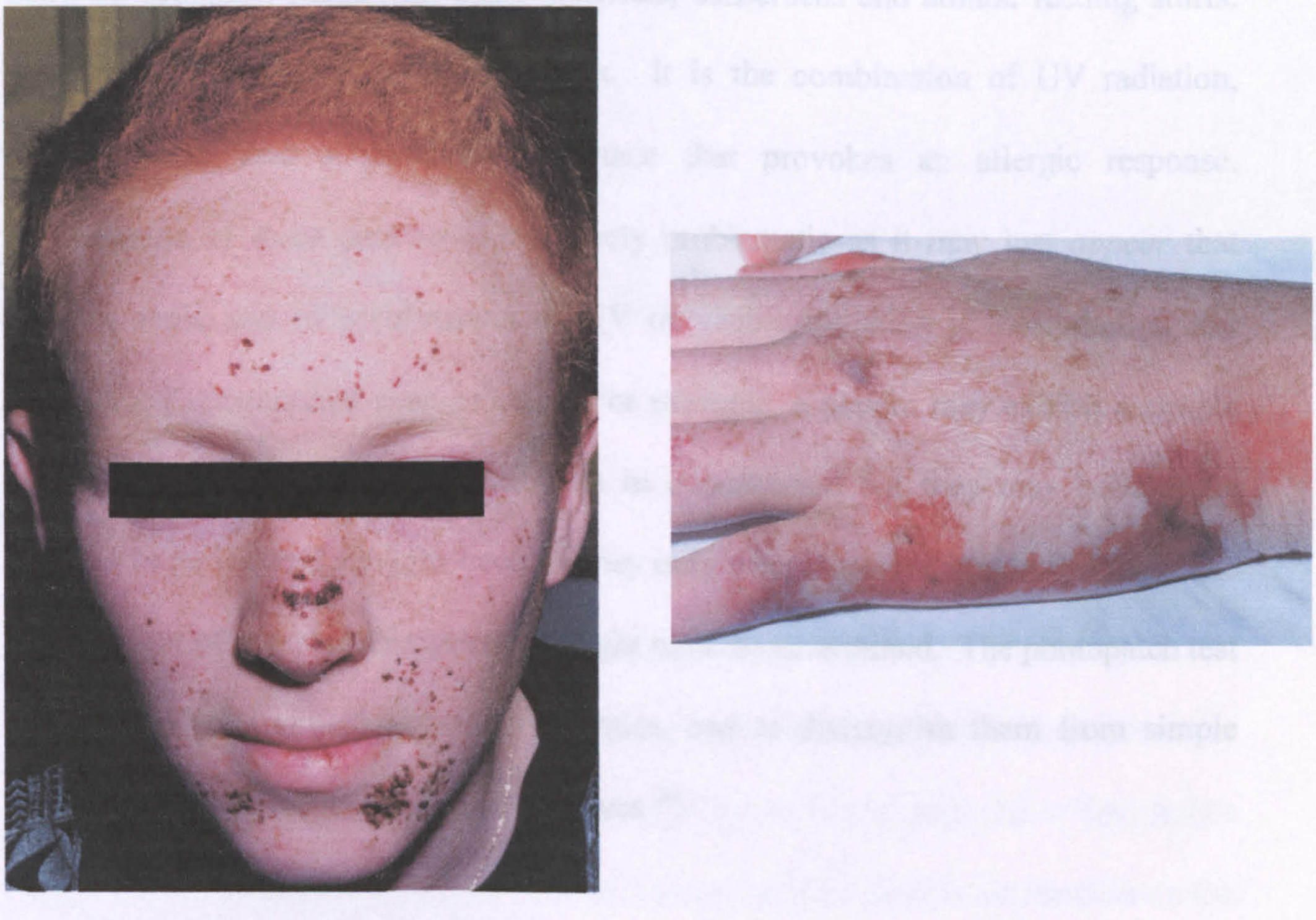
These photodermatoses are a rare group of autosomal recessive photosensitive disorders. These disorders may include exquisite photosensitivity and increased risk of malignancy [23]. Life expectancy can be dramatically reduced by these conditions e.g. xeroderma pigmentosum.

Cutaneous porphyrias

These conditions are congenital or acquired metabolic disorders which lead to accumulation of porphyrins in the body. These porphyrins have strong absorption spectra in the UV and hence lead to damage as they generate active oxygen species when they absorb UVR. There are 8 steps in the haem biosynthesis pathway. An enzyme catalyses each step. The deficiency of an enzyme may lead to one of the porphyrias. Accumulated porphyrin is excited within the blood as it flows through the skin. This can produce painful photosensitivity. The most common conditions affecting the skin are erythropoietic protoporphyria (EPP) (see figure 1.5), porphyria

cutanea tarda (PCT), and congenital erythropoietic porphyria (CEP) also known as Gunther's disease. The different porphyrias may be diagnosed by spectrofluorimetric examination of blood, urine and stool. Many of these patients exhibit sensitivity to UVA and the visible part of the spectrum. Exposure to theatre lights may trigger a reaction. In many unfortunate patients, the condition is so severe that they must wear hats, gloves and dark glasses if they venture outdoors on a summer's day. Various treatment options are available and patients often do go into remission.

Figure 1.5: Erythropoietic Protoporphyria



Chemically induced photosensitivity

Apart from the photoaggravated dermatoses the remaining causes of photosensitivity are chemically induced. There are two mechanisms for this: photoallergy and phototoxicity [25]. Phototoxic reactions are the most common and often lead to persistent pigmentation. Treatment for phototoxic reactions involves the exclusion of the agent causing the phototoxicity from the patient's environment.

True photocontact allergy should be distinguished from a non-allergic photocontact reaction. The latter occurs in all individuals exposed to a photocontact agent, such as dyes, tar products, fragrances, plant materials, sunscreens and animal feeding stuffs. True photocontact allergy is uncommon. It is the combination of UV radiation, usually UVA, and a particular substance that provokes an allergic response. Investigation of these patients is extremely problematic as it may just *appear* that there is some sort of involvement of UV or visible radiation if the radiation and allergen are encountered concurrently. For example, a patient may exhibit a simple contact allergy to one of the chemicals in a sunscreen but they may believe the reaction to be induced by light because they only wear the sunscreen in the sun. The involvement of potential allergens with light must be determined. The photopatch test is used to detect any photocontact allergies, and to distinguish them from simple contact allergies. The methodology involves [26]:

- Application of duplicate series of allergens
- Exposure of one set of allergens to sub-erythemal UVA after 24-48 hr
- Assessment of results 48 hr after irradiation

Figure 1.6: Photopatch testing. The left hand side of the woman's back has been irradiated with monochromatic wavelengths of varying dose. The right hand side of her back is shown enlarged. The upper half has been exposed to 18 different potential allergens alone; the bottom area has received these same allergens plus UV at a known level. The reactions seen on the bottom half of her back show that this patient has a photocontact allergy to some sunscreen constituents.

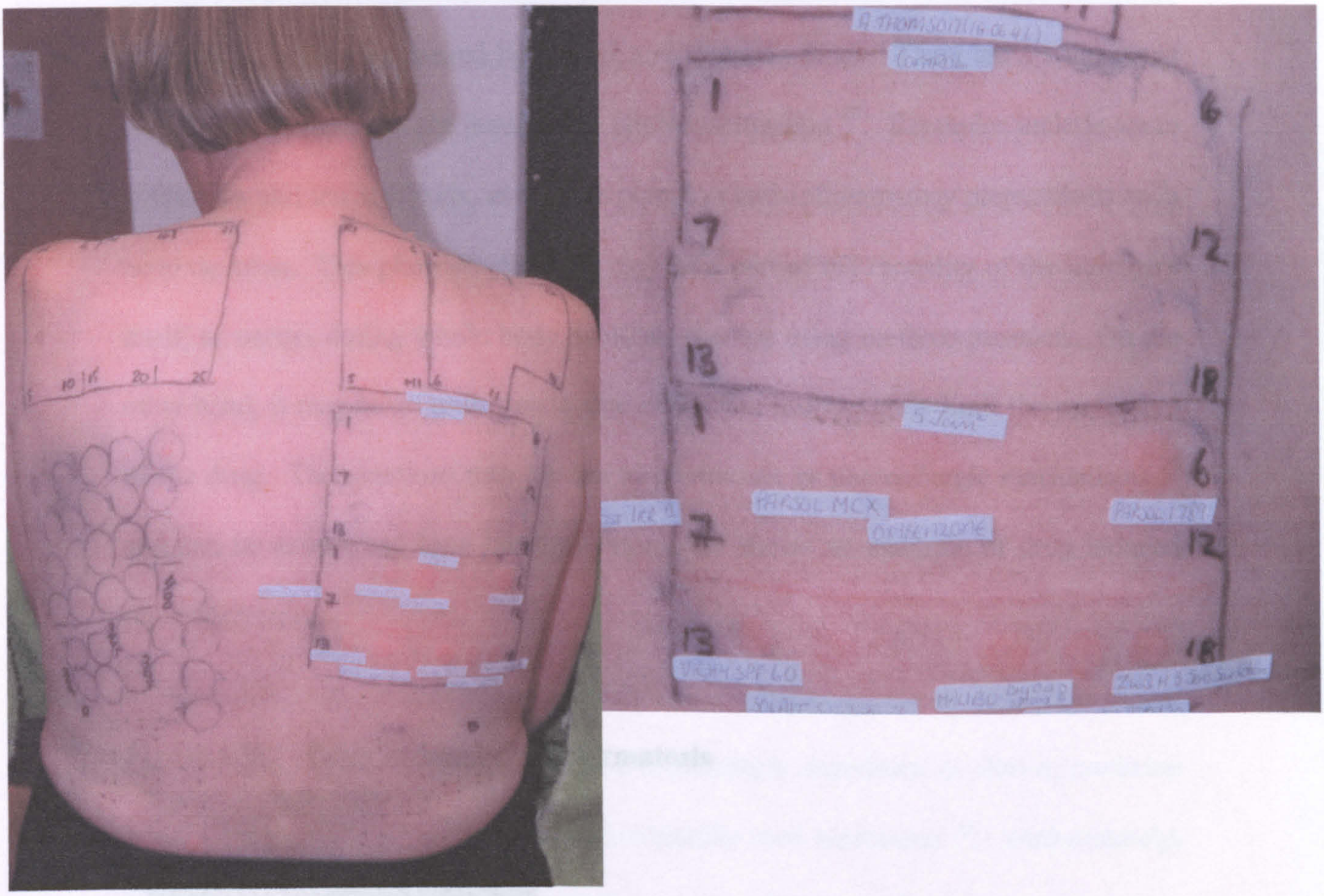
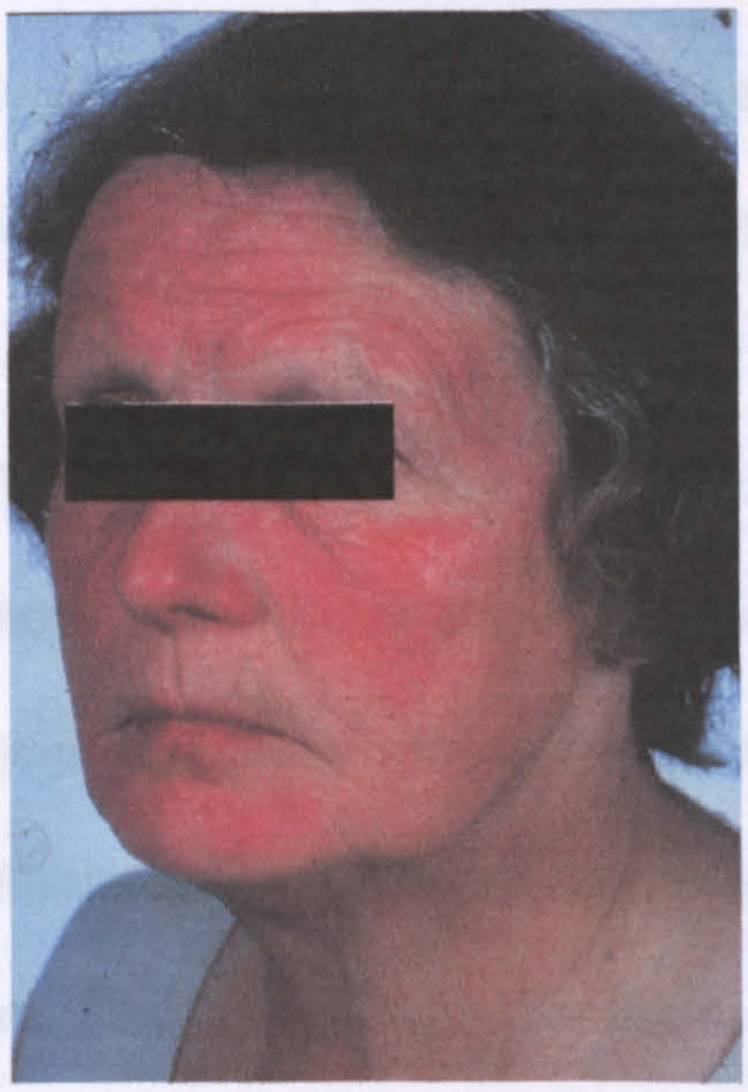


Figure 1.6 shows positive photopatch testing results to several of the chemicals commonly used in sunscreens. Sunscreen constituents are common photoallergens, [26], which is unfortunate as they are used in order to protect the skin. This lady's allergy can be diagnosed as a photocontact allergy because there is no reaction on the part of her back that was not irradiated. Other chemicals that are commonly tested because they can be photoreactive allergens are musk ambrette, coumarin and sandalwood oil. It is also commonplace to test with substances supplied by the

patient because there is sometimes an ingredient hidden amongst a vast array of constituents that is causing the problem.

Phototoxicity is an immediate or delayed inflammatory reaction that looks like severe sunburn [10]. It may be caused by topical and systemic drugs. There are a wide range of pharmaceuticals that are involved in photosensitisation [27]. Examples include some antibiotics and tranquillisers, as well as common anti-inflammatory preparations such benoxaprofen. This photosensitisation may be a part of the modality of the treatment itself, as occurs during whole body psoriasis therapy using methoxypsoralen. On the other hand, it may be an unfortunate side effect that may severely limit the usefulness of the drug. The reactions may be due to phototoxic or photoallergic mechanisms [28] and can be severe and long lasting. Figure 1.7 shows an example of drug induced photodermatosis.

Figure 1.7: Drug induced photodermatosis



In many cases photosensitising effects can be predicted by looking for structural relationships to known photosensitising drugs. In recent years, regulation has required that new drugs that have a similar structure to a known photosensitiser are proven to be non photoactive before marketing [29]. Double blind, randomised trials are required in order to determine the photosensitising potential of drugs that are attempting to become licensed for prescription. There is usually consistency in the wavelengths of radiation that will provoke a phototoxic reaction from drugs. On the basis of this information, the severity of reactions and the persistence of the drug, licensing decisions can be made. In some instances, however, photoactive compounds are licensed as drugs due to the importance of their therapeutic benefits.

The classic example of this is the fluoroquinolone antibiotics. These are a family of effective, broad spectrum antibiotics. Some members of this group of antibiotics are active against MRSA, tuberculosis and other diseases, which require virulent antibiotics to treat. These drugs may be increasingly significant in clinical medicine as disease organisms gain resistance to currently used antibiotics [30]. Unfortunately, though, many fluoroquinolones are known to cause photosensitivity.

These antibiotics were first tested in the 1980's, when they were expected to be phototoxic. Since then, tests on emerging fluoroquinolones have revealed wide ranging photosensitising potential [31-33]. In some cases, the development of these antibiotics has had to be abandoned due to their potent phototoxicity [34]. In others, the drugs are only intended for use in intensive care wards, where appropriate precautions can be taken [34].

Other antibiotics can lead to photosensitivity. Sulphonamides, nalidixic acid and tetracycline members have all been reported to be photosensitisers. In general such reactions are mild, although rarely some individuals have a severe response [35].

Photodynamic therapy (PDT) is an evolving cancer therapy. The technique involves the use of a photosensitising drug that accumulates in tumour cells, and visible light (usually laser light) to activate the drug and kill the cells. The mode of action is believed to be via the production of singlet oxygen and other reactive species. This technique is used, very successfully, to treat skin cancers where the photosensitiser may be applied topically. For the treatment of cancers where topical application is not possible, photosensitising drugs can be administered orally or intravenously. These cancers include brain tumours and lung and oesophageal cancers [36]. However, patients can be rendered photosensitive as a side effect of systemic PDT drugs [37].

One particular photosensitiser that induces photosensitivity that persists for up to 3 months after injection, is porfimer sodium (Photofrin®). Overexposure to light can lead to severe erythema. Thus patients are advised to avoid exposure, wear close weave clothes, wide brimmed hats, dark glasses and gloves at all times. These guidelines can be very limiting for patients. Clinical experience within Dundee has shown that this modality is useful both as a curative and a palliative option. In the latter case, PDT brings symptomatic relief; for example in lung cancer, it can eliminate the distressing coughing up of blood (haemoptysis). In cases where PDT is only used palliatively, the need to avoid sunlight in the few remaining active months of life places a severe restriction on its use. It is also the case that some light exposure is necessary as there is a photobleaching effect, which accelerates breakdown of the

residual drug. Thus a balance must be achieved between too much and too little exposure.

Plants can be responsible for chemically induced photosentitivity. Typically this produces a blistering reaction that often has a striated appearance arising 48 to 120 hours after plant and light exposure. Known causes include celery, parsnips, limes and giant hogweed. Children who play outdoors in the summer may be affected and this has given rise to mistaken allegations of child abuse. A condition called strimmer's dermatitis is caused by pulp from cow parsley or cow parsnip being thrown by the strimmer onto the skin [38]. Excessive consumption of celery and parsnip soup has resulted in photosensitivity [39]. Hypericum, an extract from St John's Wort, is widely used as an over-the-counter treatment for mild depression. The active ingredient, hypericin, is a photosensitiser.

Photoaggravated dermatoses

Light can aggravate already existing dermatoses such as atopic eczema [40], psoriasis, lupus eryhtematosus and lymphocytoma. Patients experiencing a worsening of their condition on exposure to sunlight have to control their exposure to manage their condition.

7. Psychological effects

The psychological effects of photodermatoses can be profound. The following case study is produced with permission of one of the most sensitive patients that attends the photobiology clinic in Dundee.

Case Study

Frank Doherty

Age 65

Mr Doherty is one of the most sensitive patients regularly seen at the Photobiology Unit. He was diagnosed with solar urticaria in 1999.

Frank worked as a roofer all his life. He resides in Glasgow and had enjoyed an active, normal life until 1993 when he suffered two minor strokes. These, coupled with some heart trouble led him to give up work in the same year.

He first noticed symptoms of his urticaria in 1998. He consulted his GP about painful swelling and itching that he was experiencing. The swelling would subside within twenty or so minutes and Frank did not manage to actually demonstrate the problem to his doctor as the symptoms would subside during the period spent in the doctor's waiting room. Frank had no idea what the cause of this unpleasant sensation was as it appeared both when he was outside and also when he had been asleep in his bed. Frank slept next to the window and used to keep the blinds open a little.

His GP tried many different combinations of drugs for his heart condition, fearing that these drugs were provoking an allergic skin reaction. He also tried many different emollient treatments for his skin. None of these attempts helped his skin and he grew increasingly frustrated with his tiresome condition. He reported that he "didn't know what to do" at the time, as no causal factor in aggravating his skin was apparent to him.

Frank was eventually referred to see a dermatologist at Glasgow Royal Infirmary. His condition was then diagnosed when a medical student observed his skin flare up as he stood next to a window in the consulting room. The consultant dermatologist had to ask him to move away from the window.

Since that consultation Frank has regularly spent time as an inpatient at the Photobiology Unit. When he first visited the unit he was diagnosed as being severely sensitive in the UVA and visible regions of the electromagnetic spectrum. This visible sensitivity explains his skin reaction from behind window glass, even in early morning sunlight coming through his open window blind. In Frank's case it is important to minimise his flare-ups, not simply because of the discomfort it causes him but also because of the risk to his heart. When his skin flares up it causes blood to rush to the skin and Frank experiences "very, very itchy, painful stinging and stretching sensation". This rush of blood accelerates his heart rate, which he says is "quite frightening".

Frank was advised to wear protective clothing (see figure 1.11) and sunscreens but he finds this very limiting. If he forgets to put gloves on to take the rubbish out to the bin then his hands will flare up. He also finds that all his clothes end up covered in suncream and in the summer, when other people are wearing shorts, he feels "like a zombie" and says that "people look at you like you've escaped from somewhere, all covered up in gloves and a hat".

Several means of managing his condition have been tried at the Unit. He has tried several antihistamine treatments with no benefit and has also tried immunosuppressing drugs. He reported "weird" symptoms from these drugs, including hallucinations. UVB and UVA desensitisation therapies have also been tried. Frank found some short-term benefit from UVA therapy but has also suffered third degree burns from the UVB therapy.

Despite these measures, Frank has become progressively more sensitive and now finds it hard to enjoy any time out of doors. He reports flare-ups from lighting in certain shops and his symptoms now take over an hour to subside. He does not find any difference in winter or summer and is now, to all intents and purposes, housebound.

Through all this adversity and inconvenience, Frank remains remarkably positive about his condition. He has found himself "special corridors and entrances" for the clinics he has to visit. These allow him to avoid external windows and minimise risk to himself. When he spends time on the dermatology ward at Ninewells he has a special bed where harmful rays are excluded. His house is also covered in plastic film to protect him. He is jovial and makes jokes about his clothing but this covers up many psychological effects. Frank can no longer holiday with his family, so they go without him. He refuses to feel sorry for himself but his last comment is telling:

"I just cannae understand it - work outside all my life and suddenly this happens".

8. Diagnosis of photosensitivity

In order to offer a patient relief from these conditions it is necessary to properly diagnose the condition. Phototesting is used as the objective basis for diagnosis of photosensitivity [41,42]. The methodology and its limitations are discussed in chapter 3. The other tool relied upon by clinicians is a detailed history from the patient with suspected photosensitivity. Important factors that are considered include:

- Skin type
- Age of onset
- Time of year the rash is the worst (and best)
- Whether tolerance occurs
- The amount of exposure required to trigger the rash
- Whether sunlight passing through a window will cause the rash
- Distribution of rash
- Time course of onset after exposure
- Appearance and symptoms of the rash
- History of sunbed use
- Family history
- Drug history
- Use of topical agents and sunscreens

If the history is detailed and unequivocal then the clinician can often be confident of a diagnosis and perform further tests simply to confirm their suspicions. In more complicated cases monochromator phototesting and provocation testing (also discussed in chapter 3) may be the only tools that are useful in unravelling a patient's condition. These tests show the wavelengths involved in a patient's condition and the extent to which they are affected i.e. how sensitive they are compared with a normal response.

9. Protection

The need for protection from wavelengths that cause sensitivity is self-evident. This is conventionally achieved by avoidance of light and the use of topical sunscreens. Alternative means of management are discussed in chapter 4.

10. Therapeutic uses of light

Optical radiation is used medically for two different purposes. Controlled exposure to UVR can desensitise patients suffering from some photosensitive skin conditions. As a means of management of photodermatoses this is discussed in chapter 4.

Exposure to UVR may also provide relief from conditions that do not directly involve light. Examples are the treatment of neonatal jaundice [43,44] and seasonal affective disorder [45,46]. Green *et al* [47] have produced an excellent review of the uses of UVR in the treatment of skin disease. Whatever the origin of the light we must have an understanding of the light that reaches our skin so that we can avoid potentially harmful effects.

11. Measurement of light for quantification and understanding of our environment and for control of therapeutic exposure

There are three main methods of measuring optical radiation [48]. These are:

- Broad band measurements
- Spectral measurement using spectroradiometry
- Personal dosimetry

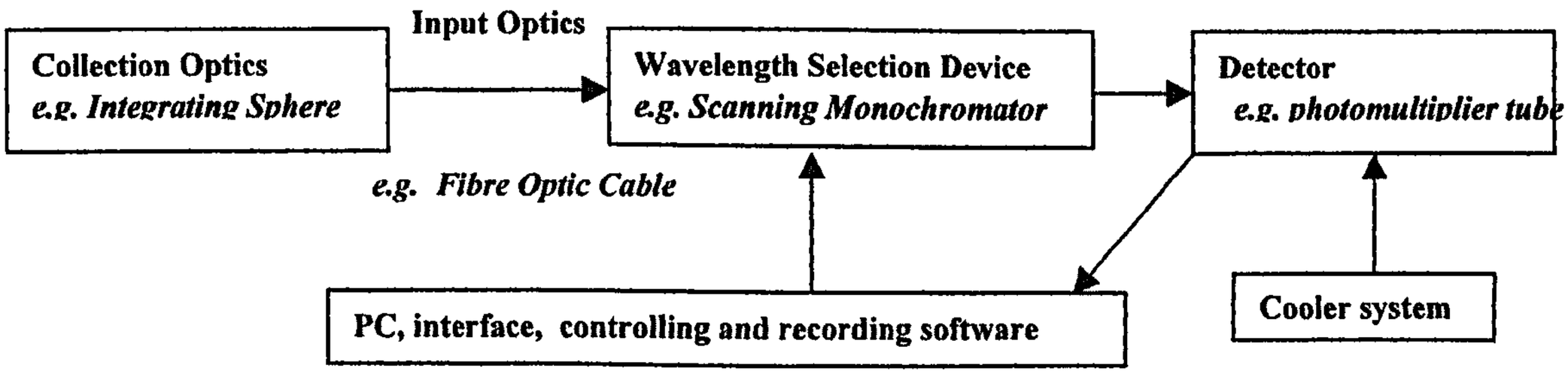
Broadband measurements are achieved using radiometers usually filtered for the wavelengths of interest. Chapter 2 discusses the limitations of this technology.

Spectroradiometry resolves the spectrum of any source that is measured. Absolute spectral irradiance measurements can be achieved at an uncertainty level of 4% [49]. However, spectroradiometers themselves are difficult to characterise and are "notoriously unstable and complex entities" [50]. Furthermore, the underlying technology involved in spectroradiometry has not advanced significantly since the 1980's [51]. Nevertheless, this technology allows us to resolve the spectrum of a source and is therefore invaluable in health hazard assessment.

Spectroradiometers consist of:

- input optics
- wavelength selection mechanism with a controlling interface
- detector

Figure 1.8 Schematic layout of a spectroradiometer



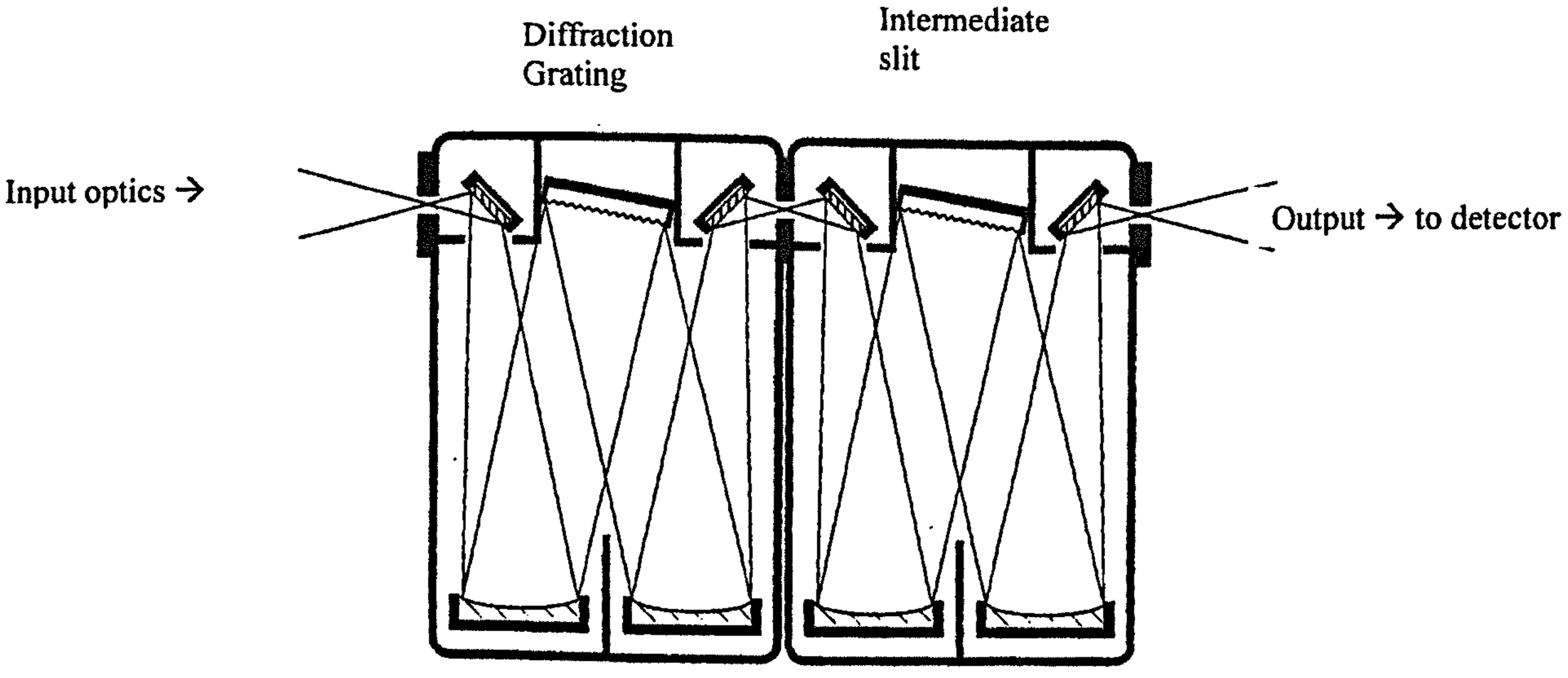
Input optics

These generally consist of flat plate diffusers, either coupled to a fibre optic cable or directly to the wavelength selection device. The other option is an integrating sphere. Either way, input optics should have a response proportional to the cosine of the incident angle of the radiation. Deviation from this perfect response has been identified as one of the major sources of error in SUV spectroradiometry often contributing to uncertainties of up to 13% in irradiance measurements above 60° [52].

Monochromators

Monochromators are wavelength selection devices that work on the principle of dispersing optical radiation and using focusing optics (i.e. spherical mirrors) to direct the path of dispersed radiation. There are several different models of monochromator but one of the most widely used and best understood is the Czerny-Turner layout. Figure 1.9 shows the general optical layout of a Czerny-Turner monchromator.

Figure 1.9 Optical layout of a Czerny-Turner monchromator



Reflective diffraction gratings are made up of microscopic series of reflecting and non reflecting lines which cause incident radiation to be dispersed according to its wavelength and the angle of incidence. In this way, the gratings act as the wavelength selection device in the monochromator. Gratings are mounted on turntables which allow them to be moved so that incoming radiation is incident on the grating at different angles. Therefore, if interfaced with a computer control system, the entire spectrum of interest can be scanned. Typical gratings used for the selection of UV light, have 1200 grooves per mm and are blazed at an angle such that optimal diffraction occurs at 250 nm. These gratings allow measurement of a wavelength range from 200 to 500 nm.

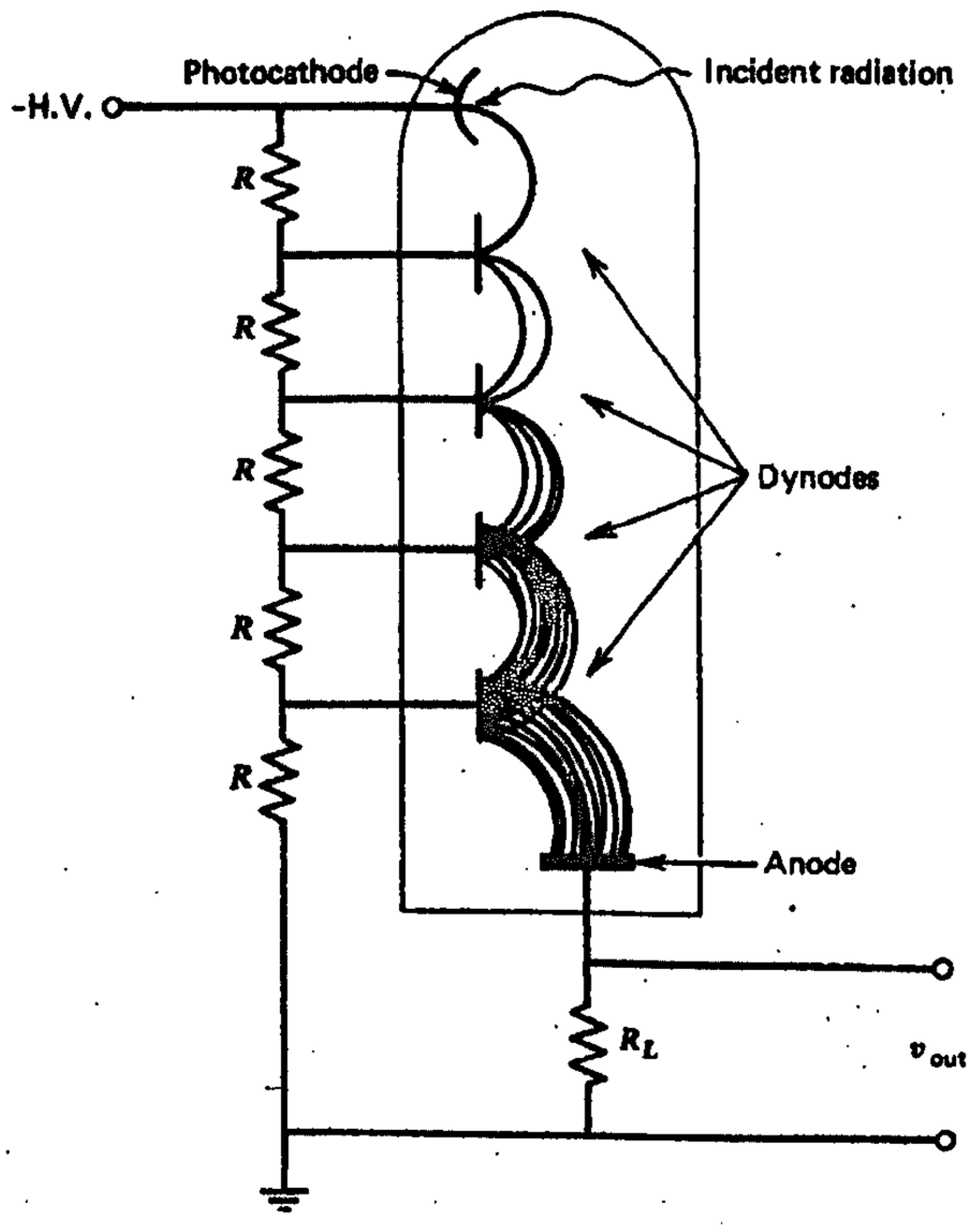
The upkeep of monochromators is very important in maintaining their accuracy [53]. Design specifications will also affect the performance and responsivity of monochromators. Defined slits at the input and the exit of monochromators are designed to exclude stray light from the system. The double grating set up of the Czerny-Turner monochromator is similarly designed to minimise stray light levels. Stray light in spectrometers is cited as one of the major sources of error in UVR spectral measurements [54].

Detectors

The photomultiplier is the most sensitive type of detector. Figure 1.9 shows a schematic diagram of a photomultiplier tube. Incident radiation causes emission of a high-energy primary electron, from the photocathode, which is then accelerated towards the higher potential dynodes, where a cascade effect causes amplification of

the signal by release of more, lower energy electrons [55]. This amplification chain makes the photomultiplier sensitive to even tiny amounts of incoming radiation and makes it the detector of choice when low level radiation has to be measured [56].

Figure 1.10 Photomultiplier schematic from Boyd [55].



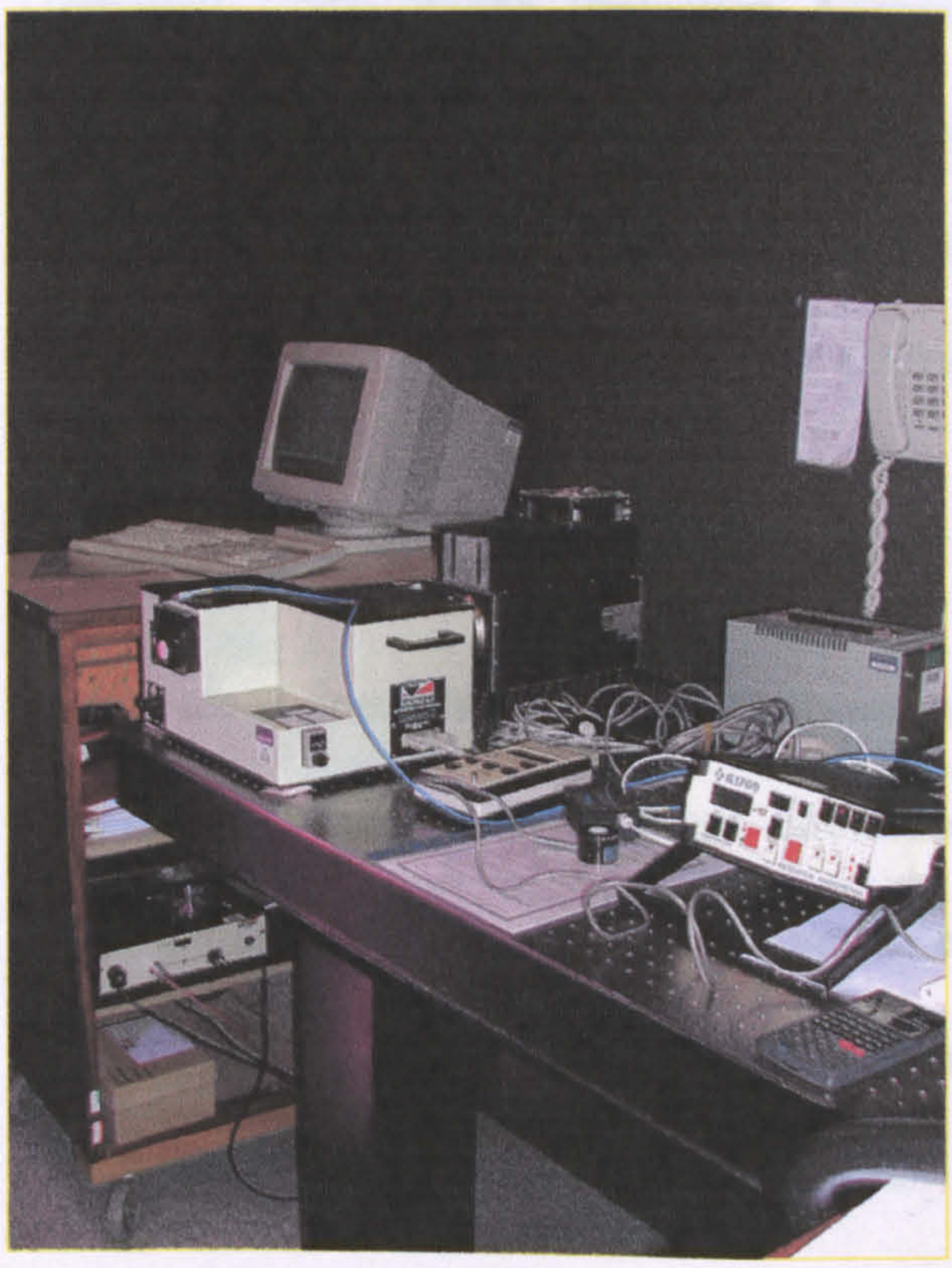
Apart from the work needed to assure measurements and maintain a spectroradiometer, the main drawback is that these instruments are bulky and lack portability.

Unless stated, measurements presented in this thesis were made using a bench based double grating spectroradiometer (Bentham DM150). This is the unit's standard for optical radiation measurement. Flat plate diffusers are used as the input optics. A

Teflon diffuser is used for UVB measurements and a quartz glass diffuser for UVA and visible light measurements.

The calibration of the Bentham is traceable to the National Physical Laboratory (NPL) and has an estimated expanded uncertainty at the 95% confidence level, of 5.72 % in UVB and 3.48 % in UVA. These uncertainties have been calculated in accordance with NPL guidelines (Bell 2001) and include consideration of the uncertainty in the calibration sources used, alignment errors and uncertainty in the current from the cooled (-20° C +/- 2° C) photomultiplier tube. The uncertainty budget has also received accreditation from the United Kingdom Accreditation Society (UKAS) when the department's UV meter calibrations were evaluated and accredited. The transfer standard for radiation measurements from 315 to 800 nm is a 100 W, frosted glass, tungsten lamp and a 30 W deuterium discharge lamp is used as a transfer standard for UVB (280-315 nm).

Figure 1.11 The photolaboratory in Dundee, showing the Bentham DM150



Studies of personal phototherapy source dosimetry have been conducted, primarily using polysulphone film badges [57-59] since their introduction as personal dosemeters for UV radiation [60]. These badges can provide useful information regarding the distribution of phototherapy radiation over a patient's skin. Other commercial personal dosemeters incorporating UV sensitivity are available. These are generally based on solid state detector technology e.g. the sp3 (Tunbridge Wells, Kent) 'Sunwatch'™ which is based on a solid state gallium nitride detector.

12. Regulation of light exposure

In the UK there are no specific laws covering exposure to optical radiation. Two main bodies are involved in the production of exposure guidelines. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) is scientific body that aims to disseminate information on the potential health hazards of exposure to optical radiation. The Health Protection Agency is a a non-departmental public body encompassing the old National Radiological Protection Board (NRPB). It has protection of exposure to optical radiation as part of its remit. Other groups such as the British Photodermatology Group (BPG) produce guidance on exposure to UV sources used therapeutically.

There are various publications from these and other international bodies that deal with exposure to sources in different circumstances. These are discussed in context throughout this thesis. Of note is that the exposure limits published do not consider abnormal skin. Thus, for individuals with specific photosensitivities, symptoms may occur below recommended exposure limits.

13. Structure of thesis

Chapter 2 presents an evaluation of new handheld spectroradiometers for phototherapy dosimetry. One of the instruments evaluated was found to be suitable for the measurement of clinical sources for hazard assessment and dosimetry.

In chapter 3 results from a study aiming to predict the responses of normal and abnormal skin are discussed. It was found that it was not possible to predict responses using measurements made with current instruments and methodologies. This may mean that the conditions evaluated do not respond in a linear manner to optical radiation and challenges a central premise in photobiology.

In chapter 4 results from a study to evaluate the protective efficacy of commercial cosmetic preparations for photosensitive skin are discussed. Based on the findings in this study, cosmetics are a novel tool for the management of photosensitivity.

Chapter 5 shows results of a study conducted in all the commercial and council premises offering sunbeds for tanning in two local authority areas in Dundee. The instrument evaluated in chapter 2 was used to measure the spectral irradiance of all the sunbeds. The relative and absolute spectral intensities were compared with the British Standard for ultraviolet tanning equipment. The available lengths of sessions were also recorded and the dose of radiation that would be received from each bed was calculated and existing exposure guidelines evaluated on the basis of these guidelines.

Chapter 6 presents results from a case where an UV source was being used inappropriately in an hotel kitchen. The source was measured and an evaluation of the hazards that employees had been exposed to was made. This was achieved using relevant action spectra.

In chapter 7 the main findings from the work undertaken are summarised. Areas for further investigation are also suggested.

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Chapter 2

Measurement of clinical sources

Evaluation of new handheld spectroradiometers for phototherapy dosimetry

Summary

This chapter discusses the need for accurate dosimetry in phototherapy and the limitations of current technology. Results are presented from an evaluation that assessed the potential of two diode array spectroradiometers for use in phototherapy dosimetry [1]. It is shown that this technology has significant scope for use in photodermatology provided that accuracy and calibration are carefully considered.

1. Introduction

Within photomedicine, the need for accurate dosimetry of therapeutic UV radiation has long been recognised [2,3]. Clinical applications of light are discussed in chapter 1, section 10 and chapter 4.

Excessive numbers of treatments can significantly increase the risk of carcino-genesis [4]. Thus, the minimum number of treatments for maximum therapeutic benefit is the aim in phototherapy. Accurate dosimetry is necessary to achieve this aim. Furthermore, if the dosimetry is accurate, then a patient should be able to transfer

treatment centres without jeopardising their treatment and different treatment regimens can be compared between centres [5,6].

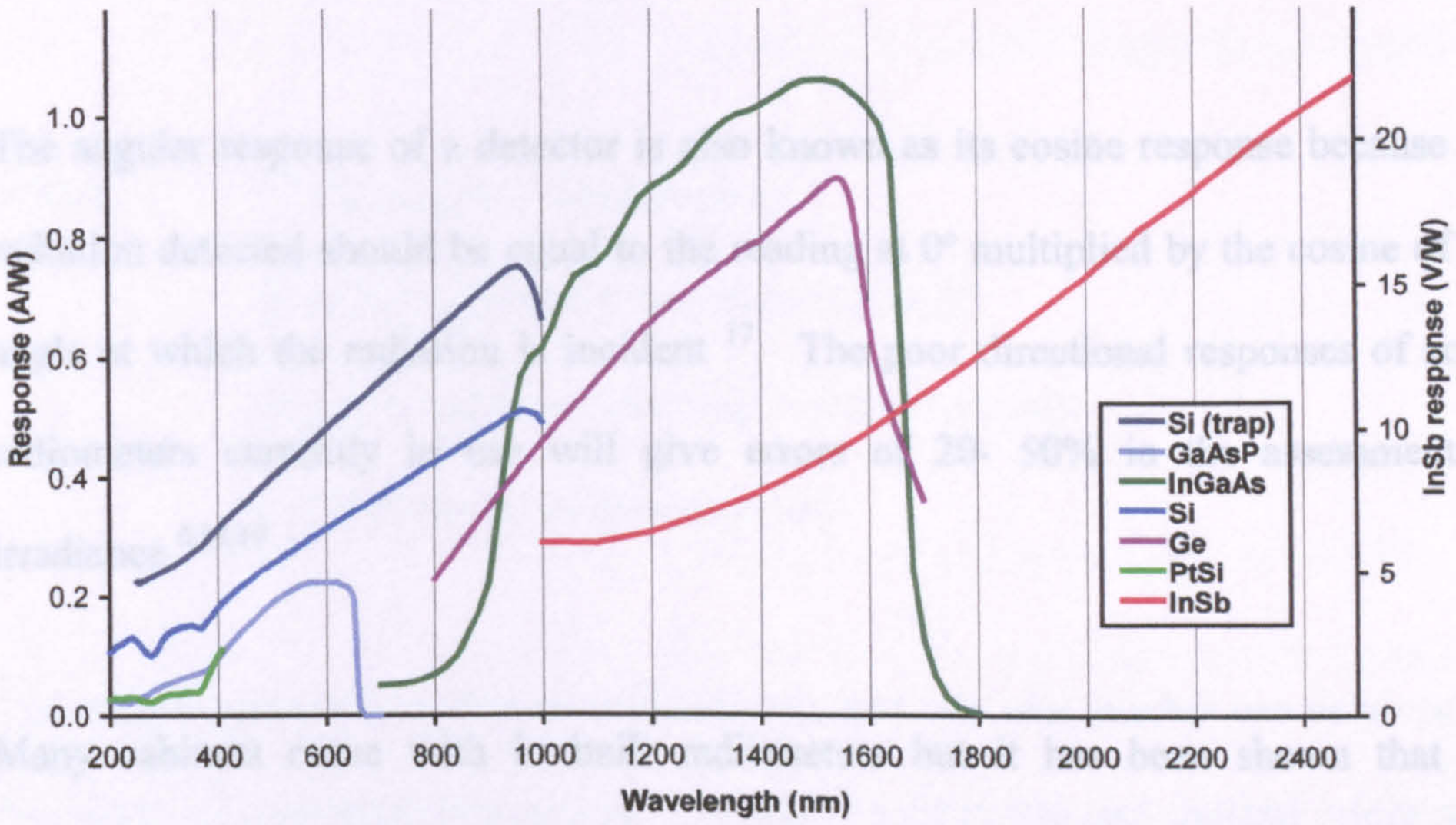
Best practice in photodermatology relies on measurement of the patient's MED or MPD, in order to determine a starting dose for treatment [7]. If the patient then receives a dose that is significantly lower than 70% of their MED/MPD it will not have the desired therapeutic benefit for the patient [8,9]. Conversely, a dose of radiation that is greater than the patient's MED/MPD can lead to a painful burn [10,11]. Hence, the dosimetry of MED/MPD testing sources must be directly comparable to that of the treatment source and both must be accurate.

Any instrument that is used for dosimetry should measure to within +/- 10% [12,13] because errors in dosimetry are clinically significant and may lead to painful erythematous reactions. For this level of accuracy to be achievable the calibration of a meter for itself should be reproducible and also traceable to national standards.

The instrument of choice is the filtered radiometer. These robust, portable, compact detectors are generally stable and exhibit the same response for decades [14]. Different photodiodes exhibit different spectral responses, as can be seen in figure 2.1. Silicon detectors are most often used for phototherapy sources. Filters can be fitted in order to ensure that the detector measures only across a finite wavelength range. However, the use of filtered radiometers requires that the spectrum of the lamp being measured is known. Effective irradiance can be measured using appropriate filters but the similarity between a radiometer's spectral responsivity and an action spectrum can be poor, resulting in large errors in measurement [15].

Figure 2.1: The spectral responses of some photodiode detectors.

Kindly supplied by Dr L Rogers, NPL.



Achieving traceable and consistent calibration of filtered radiometers is often an involved process and frequently results in one calibration specific to the measurement of one type of phototherapy source. This is good practice as CIE guidelines recommend that calibrations be performed against a source with a similar spectrum to the spectrum of the source to be measured [16]. However, confusion and resulting mistakes made when picking the calibration factor, radiometer and filter combination could easily lead to errors in patient doses if the wrong combination were used. Changes in output of phototherapy sources above the 10% level should lead to change in patient irradiation times to avoid adverse effects [13]. Errors greater than this could easily result from a mistake in picking the calibration factor, radiometer and filter combination.

Phototherapy sources are diffuse, wide angled (often 360°) and non directional, thus it is important that any instrument used in dosimetry will detect radiation from all the input angles over which radiation will be incident on the skin. This is approximated to 180° for practical reasons.

The angular response of a detector is also known as its cosine response because the radiation detected should be equal to the reading at 0° multiplied by the cosine of the angle at which the radiation is incident [17]. The poor directional responses of some radiometers currently in use will give errors of 20- 50% in the assessment of irradiance [6,18,19].

Many cabinets come with in built radiometers but it has been shown that the dosimetry of these and conventional radiometry methods can vary by as much as 60% [7]. This is possibly due to the poor angular response of the in built radiometer.

A practical evaluation of the cosine response of a detector is achieved by calculating the f2 value for the detector. The f2 value gives a measure of the total error that can be expected when using the detector to measure an 180° source. The most common error in angular response is underestimation of radiation input from wide angles [20]. The accepted expectation of radiometers used in dosimetry is that they have an f2 value of 10% or better [13,13,21].

The f2 value is calculated such:

$$f2 = \frac{\sum \left| 1 - \frac{R_\theta}{R_0 \cos\theta} \right|}{n} \times 100$$ **Equation 2.1**

Where θ is the angle of measurement

R_0 is the response of the instrument at 0°

R_θ is the response at the angle of measurement

n is the number of measurements

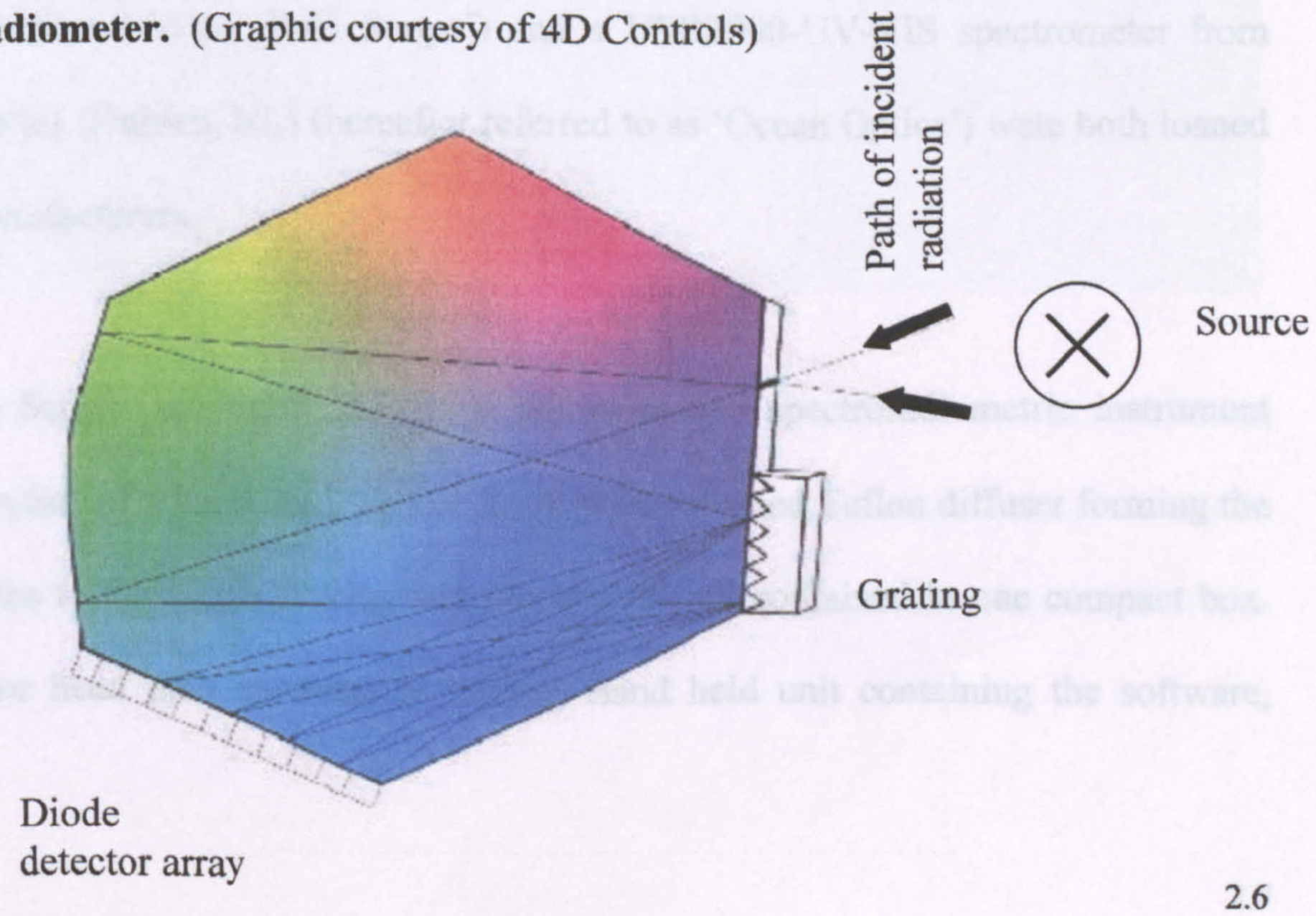
The main limitation of a filtered radiometer is that only one number can be given for the output of a phototherapy source. This can be restrictive and spectral information gives much more scope for analysis.

Absolute spectral irradiance measurements can be achieved at an uncertainty level of 4% in spectroradiometry [17] but the technique involves expensive, bulky and complex equipment and can require a large period of time to take measurements. Within a busy treatment centre, transporting bulky equipment to measure outputs from phototherapy sources is impractical. It is also thought that with phototherapy sources, providing the spectrum of the source is known then it is not necessary to make spectral measurements as changes in the source's relative spectrum are thought to be insignificant [5].

The relatively new technology of the diode array spectroradiometer offers a potential solution for dosimetry in the 21st century: an answer to the trade-off between spectral data collected with a cumbersome instrument and the ease and speed of the filtered radiometer - a portable instrument that will acquire spectral data [22]. Furthermore, this type of technology may allow the calibration of standard lamps to be transferred directly to a spectroradiometer, therefore removing a step from the calibration chain and potentially reducing uncertainty. This would also remove the need for a different calibration factor for each phototherapy source and reduce potential for confusion.

An example of the optical layout of such a spectroradiometer is shown in figure 2.2. After incoming radiation has been resolved into its constituent wavelengths by a diffraction grating, a series of fixed, solid state photodetector elements transduce the radiation into an electrical signal. As all the elements have fixed positions, it is possible to predict the wavelengths that will fall on each detector element and a spectrum can therefore be determined using appropriate software.

Figure 2.2: Diagram showing the optical layout of a diode array spectroradiometer. (Graphic courtesy of 4D Controls)



In order for this type of instrument to become widely used in the medical field, the usability, accuracy, reliability and limitations of the technology had to be assessed. If diode array instruments are to become the dosimetry instrument of choice in the future and filtered radiometers are to be usurped then the same requirements for accuracy should apply in both cases.

During 2001 and 2002 two diode array instruments, from different manufacturers were evaluated. This work was published in 2002 [1]. A number of investigations were carried out to assess the performance parameters of these instruments. As regards these portable, spectral instruments, three specific areas of performance were identified as meriting investigation. The calibration, stray light rejection and angular response of the instruments were thought to present, potentially, the largest sources of error in using the instruments.

2. Methods and materials

An UV Spectroradiometer: Type SC-MP-A, from 4D Controls (Redruth, UK) (herefter referred to as 'Sola Scope') and a USB2000-UV-VIS spectrometer from Ocean Optics (Duiven, NL) (hereafter referred to as 'Ocean Optics') were both loaned by the manufacturers.

The Sola Scope (see figure 2.3) is a self contained spectroradiometric instrument which consists of a hand held 'sensor head' with a domed Teflon diffuser forming the input optics to the single grating and diode array, all contained in one compact box. The sensor head then connects to another hand held unit containing the software,

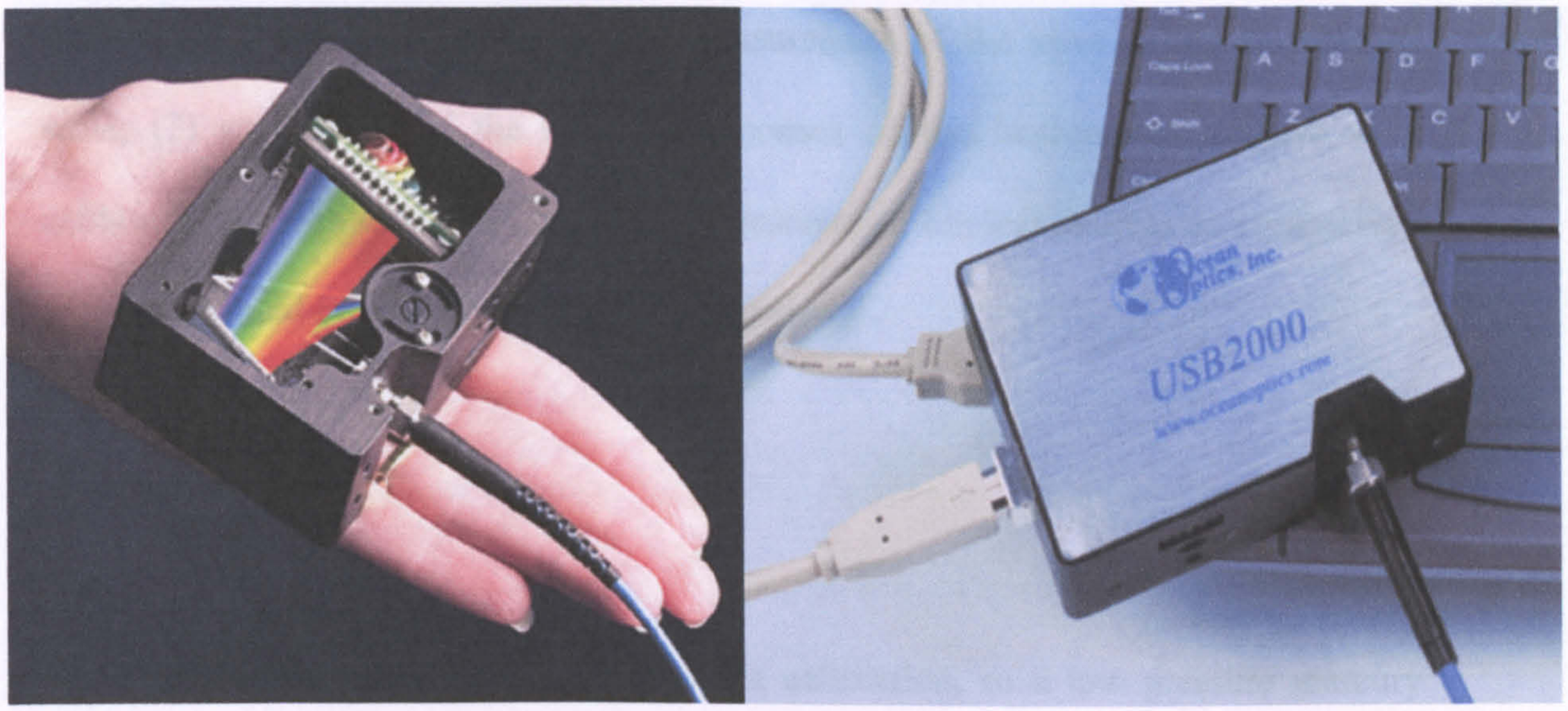
control keypad and a display panel to enable spectra of measured lamps to be visualised. Data from the Sola Scope can be easily uploaded to a PC spreadsheet for analysis via supplied (Sola-Term 2000) software.

Figure 2.3: Sola Scope 2000 as supplied by 4D controls Ltd. (Picture courtesy of 4D controls).

The Ocean Optics (see figure 2.4) consists of a flat Teflon diffuser head attached to an optical fibre that forms the input optics to the spectrometer (a single grating and diode array), which is a unit no bigger than a pack of cards. The spectrometer connects to a

laptop PC via a USB port and the spectrometer can then be controlled using supplied (OOIBase32) software.

Figure 2.4: Ocean Optics. Optical layout and instrument connected to a PC. (Courtesy of Ocean Optics).



The instruments differ slightly in their mode of use. The Ocean Optics was designed for use as a comparative radiometer, or spectrometer. The idea is to use a standard reference lamp to record a spectrum in the software. The standard lamp's colour temperature can then be input into the software and during any subsequent measurement the software derives the measured lamp's spectrum from the colour temperature profile (based on a black body emission spectrum) of the standard reference lamp. The Sola Scope is sold as a calibrated instrument that will give readings in absolute units, traceable to NPL.

Assessment of calibration

According to best practice guidelines, the calibration of instruments for use in dosimetry must be traceable to national standards [12]. This can be achieved by comparing measurements with a calibrated, double grating, bench based spectroradiometerand ensuring agreement. The requirement for traceability was tested by three different methods: (1) measurement of the error in the wavelength scale, (2) assessment of the spectral responses of the instruments, relative to a calibrated spectroradiometer and (3) measurement of clinical sources in comparison with a calibrated radiometer or spectroradiometer.

Wavelength

The Ocean Optics was not supplied with a calibration, so a low pressure mercury lamp was used to set the wavelength scale on the instrument. The position of eight known spectral lines (between 253.65 nm and 579.07 nm) and the diode array element that detected these lines were analysed by linear regression. The regression coefficients were then input into the software and the wavelength scale was calculated.

The same lamp was used to test the supplied wavelength scale on the Sola Scope.

Spectral Responsivity

The relative spectral response of both instruments was assessed by measurement of a 1 kW incandescent quartz halogen lamp (designated type FEL) calibrated at NPL. The lamp was allowed 30 minutes warm-up time and was run at a current of 8.33 A. The instrument's response at each wavelength was compared to the maximum response to give a spectrum of the instrument's relative response.

This same measurement was used to form a calibration for both instruments. The correction (SF) at each wavelength (λ) was determined such:

$$SF_\lambda = \frac{E_\lambda}{R_\lambda} \qquad \textbf{Equation 2.2}$$

where: SF_λ is the sensitivity factor at a given wavelength

E_λ is the lamp irradiance at the same wavelength

R_λ is the instrument response at that wavelength

Stray light performance

One of the aspects most likely to limit the accuracy of these instruments is their stray light performance. In the case of diode array instruments, stray light is radiation that is detected by the 'wrong' element for the wavelength of the radiation due to reflections inside the instrument. Commonly, longer wavelength radiation is reflected internally and falls on elements that are arranged to detect only short wavelengths. This phenomenon is common to spectroradiometric systems although in the case of

bench based spectroradiometers, two successive gratings may be used to improve the wavelength selection and prevent inappropriate wavelengths from reaching the detector. The trade-off from having better wavelength selection, however, is that signal levels are substantially reduced and thus a sensitive detector (such as a photomultiplier) must be employed. Diode array instruments are single grating, portable instruments and as such would be expected to have poor stray light levels which will affect the overall calculated dose for any phototherapy instrument.

Stray light levels were assessed in theses instruments by the use of a Xenon Arc lamp, filtered for infrared radiation (IR) with an H_2SO_4•$CuSO_4$ solution and a cut on filter (WG305, Schott). The lamp was allowed at least 15 minutes to stabilise before the spectra were measured by the diode array instruments. The advantage of using a source with a broad spectral output is the fact that stray light contributions from longer wavelengths, which may be detected as short wavelengths, can be identified more easily than if a monochromatic source or a source with clear emission lines is used. As the filter has a well known transmission profile; the stray light present in the recorded spectra can be expressed as a ratio of the signal level at a given wavelength [23].

There is a method recommended by the manufacturer to correct for the stray light in the signal recorded from the Sola Scope. This method involves using an orange filter that only transmits radiation above 430 nm. The filter is placed over the input optics of the Sola Scope and the resulting irradiance profile is then subtracted from subsequent scans. This procedure must be repeated before each lamp measurement

because there will be a different stray light 'profile' according to the spectral distribution of the lamp of interest.

There is no method to remove stray light from the Ocean Optics instrument although the same procedure may be applicable. The calibration derived from the 1 kW FEL lamp should calibrate out the stray light levels in the signal although this will be subject to some error due to the differing stray light 'profiles' of the calibration source compared to what is measured. A recording of the dark spectrum was made before each measurement run and the dark current or noise is therefore subtracted from each spectrum.

Measurement of clinical sources

In order to assess the reliability of these instruments in clinical practice, the calibration of the instrument and the influence of its angular and spectral responses were checked by measuring a number of phototherapy sources against calibrated radiometers or a spectroradiometer. The sources measured ranged from whole body treatment cabinets to single fluorescent tubes. These measurements were made at a nominal distance of 30 cm from the source and at least 5 minutes was always allowed for the output from the lamps to stabilise.

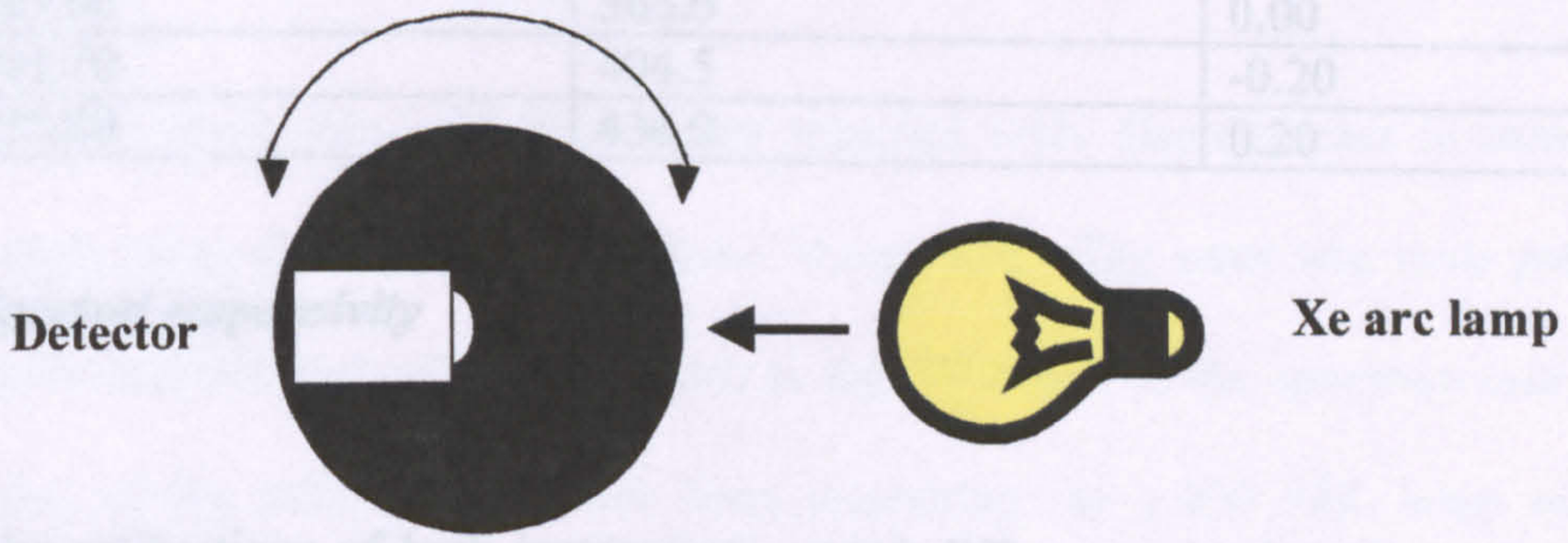
Measurements were made in direct comparison with either the Unit's IL1400 radiometer (Able Instruments, Reading, UK), which has attachments for measuring both UVA and UVB; or a bench based double grating spectroradiometer (Bentham DM150). In accordance with guidelines, the radiometer was calibrated against

sources with similar spectral outputs to those to be measured [16], in direct comparison with the Bentham spectroradiometer. The calibration of the Bentham is discussed in chapter 9. Its calibration is traceable to NPL and it boasts a cooled (-20° C +/- 1° C) photomultiplier tube and double grating monochromator.

Angular response

A measurement of the angular response of the instruments was made using a Xenon arc lamp. The lamp (as used for assessing stray light) was allowed 15 minutes to stabilise after ignition. The instruments were positioned with the input optics at the centre of rotation of a turntable. The turntable is marked at 1° intervals. The turntable was moved manually and a spectrum was recorded at each 5° step over the interval +/- 60° (see figure 2.5).

Figure 2.5: Layout of angular response measurement



The angular response of the Sola Scope was measured in the planes parallel to the grating and perpendicular to the grating. The response of the Ocean Optics was

considered in one orientation only as there is an optical fibre coupled to the diffuser so that all radiation is scrambled within the fibre.

3. Results

Assessment of calibration

Wavelength

Wavelength error for the Sola Scope is shown in table 1 and was satisfactorily small to be considered negligible.

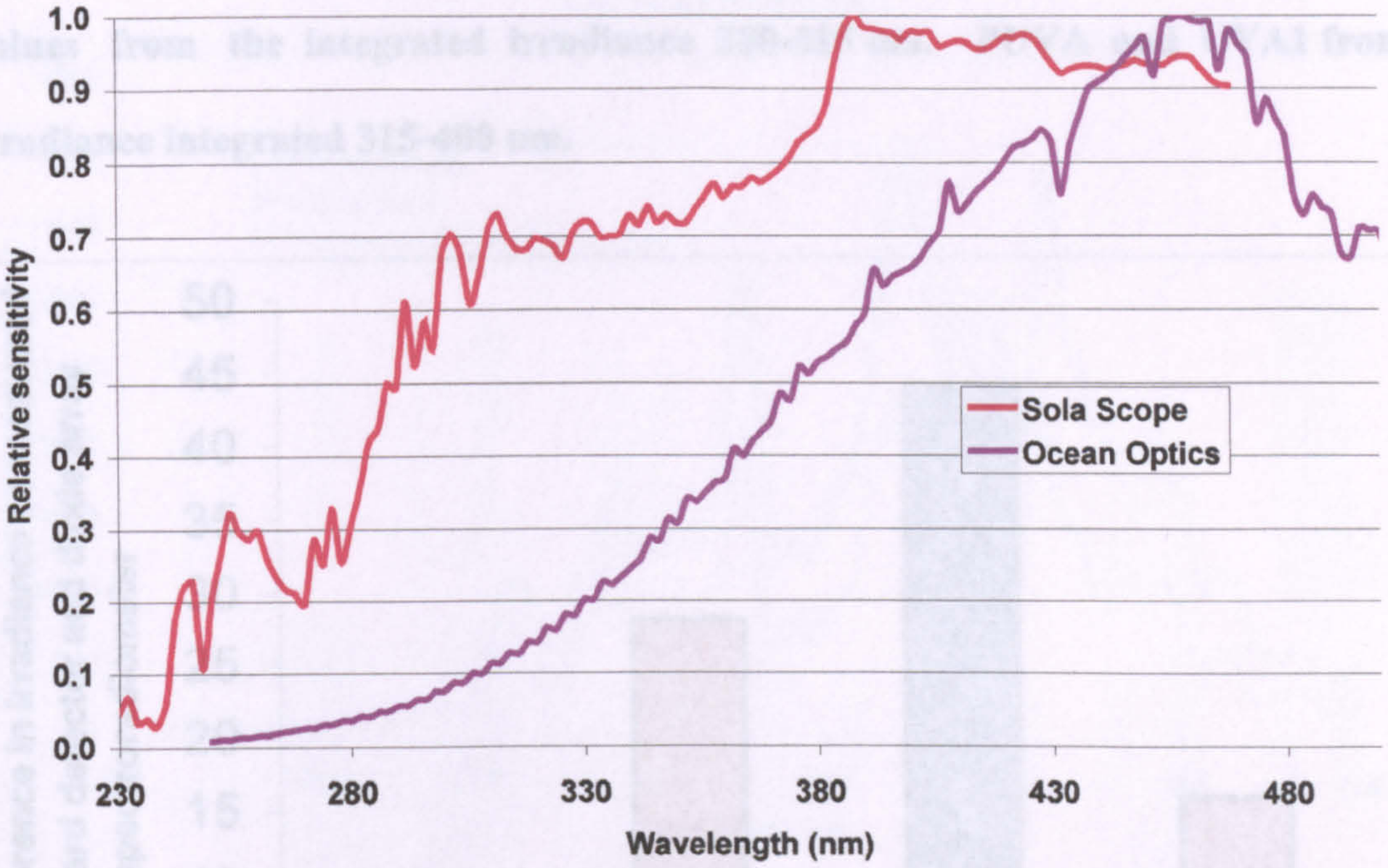
Table 1: Wavelength error of Sola Scope

Spectral line (nm)	Recorded position (nm)	Error (nm)
253.65	253.5	-0.15
313.10	313.0	-0.10
365.00	365.0	0.00
404.70	404.5	-0.20
435.80	436.0	0.20

Spectral responsivity

The calibrations of both instruments reveal differences in the relative responsivities (see figure 2.6). There was a noteworthy amount of noise in the signals from both instruments.

Figure 2.6: Graph showing the relative spectral responsivities of both the Ocean Optics and the Sola Scope.



Measurement of clinical sources

Results from using the Sola Scope revealed wide discrepancies in measured doses when using the supplied calibration (figure 2.7). The error was most pronounced as an overestimation of the irradiance at the UVA end of the spectrum (see figure 2.8). Use of the calibration created from measuring the 1 kW FEL lamp reduced these errors significantly (figures 2.8 & 2.9).

Figure 2.7: Graph to show the differences in measured irradiances when comparing manufacturer calibrated Sola Scope with IL1400 radiometer and, in the case of the UVA1 lamp, the Bentham spectroradiometer. TLO1 and TL12 values from the integrated irradiance 280-315 nm. PUVA and UVA1 from irradiance integrated 315-400 nm.

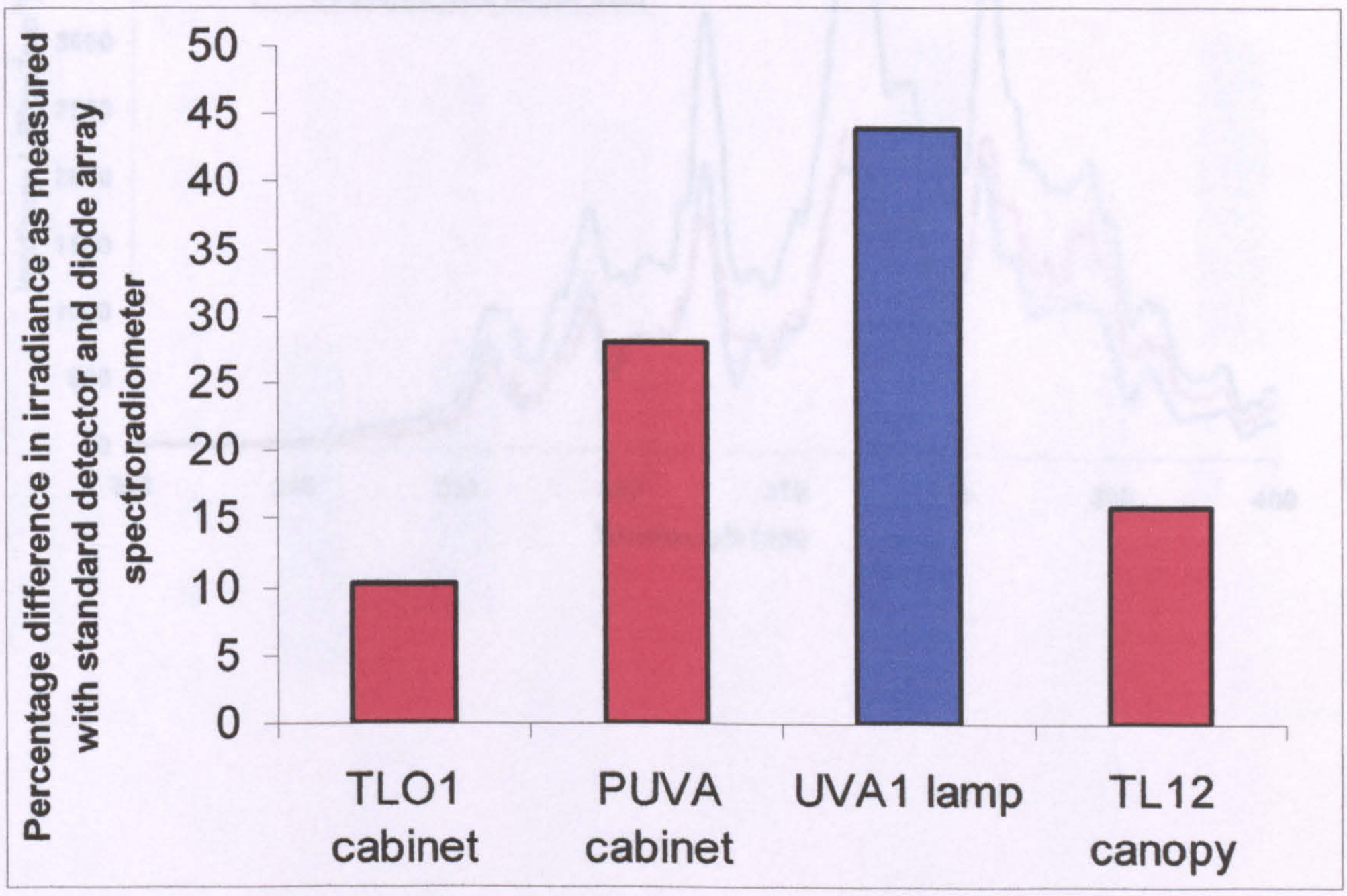


Figure 2.8: Measurement of a high dose UVA1 source, which illustrates the discrepancy that was seen to exist with the Sola Scope's supplied calibration.

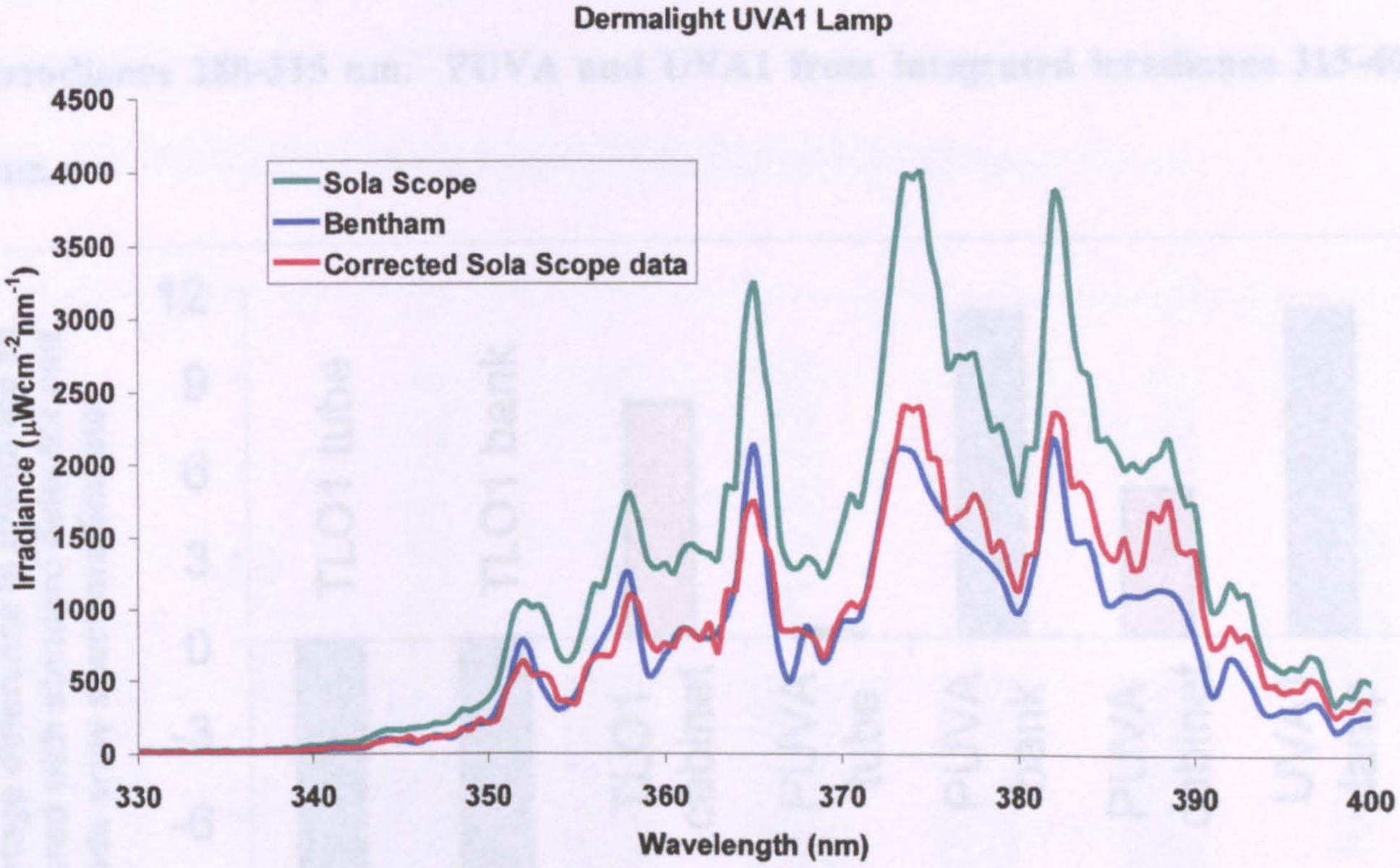
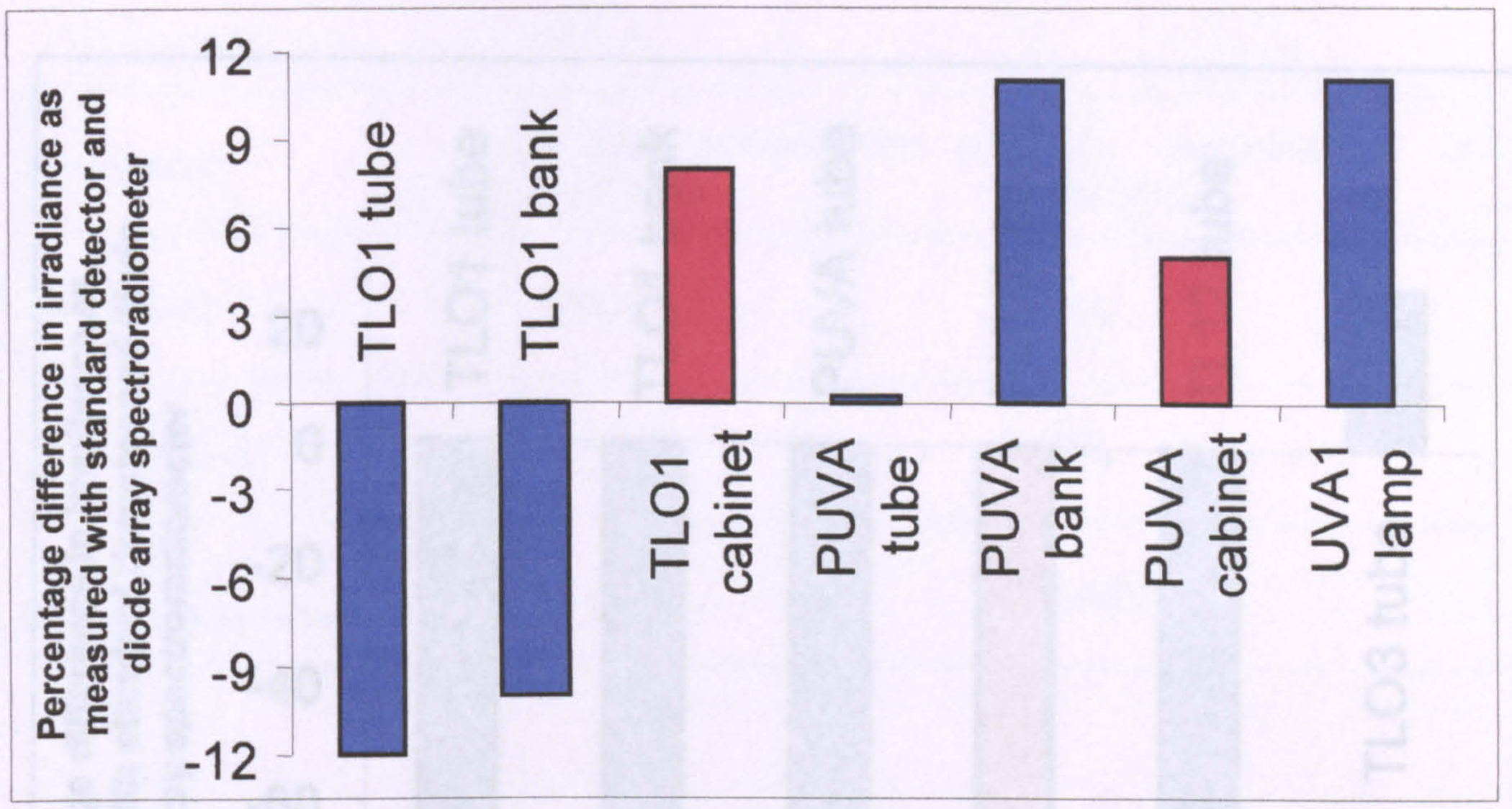
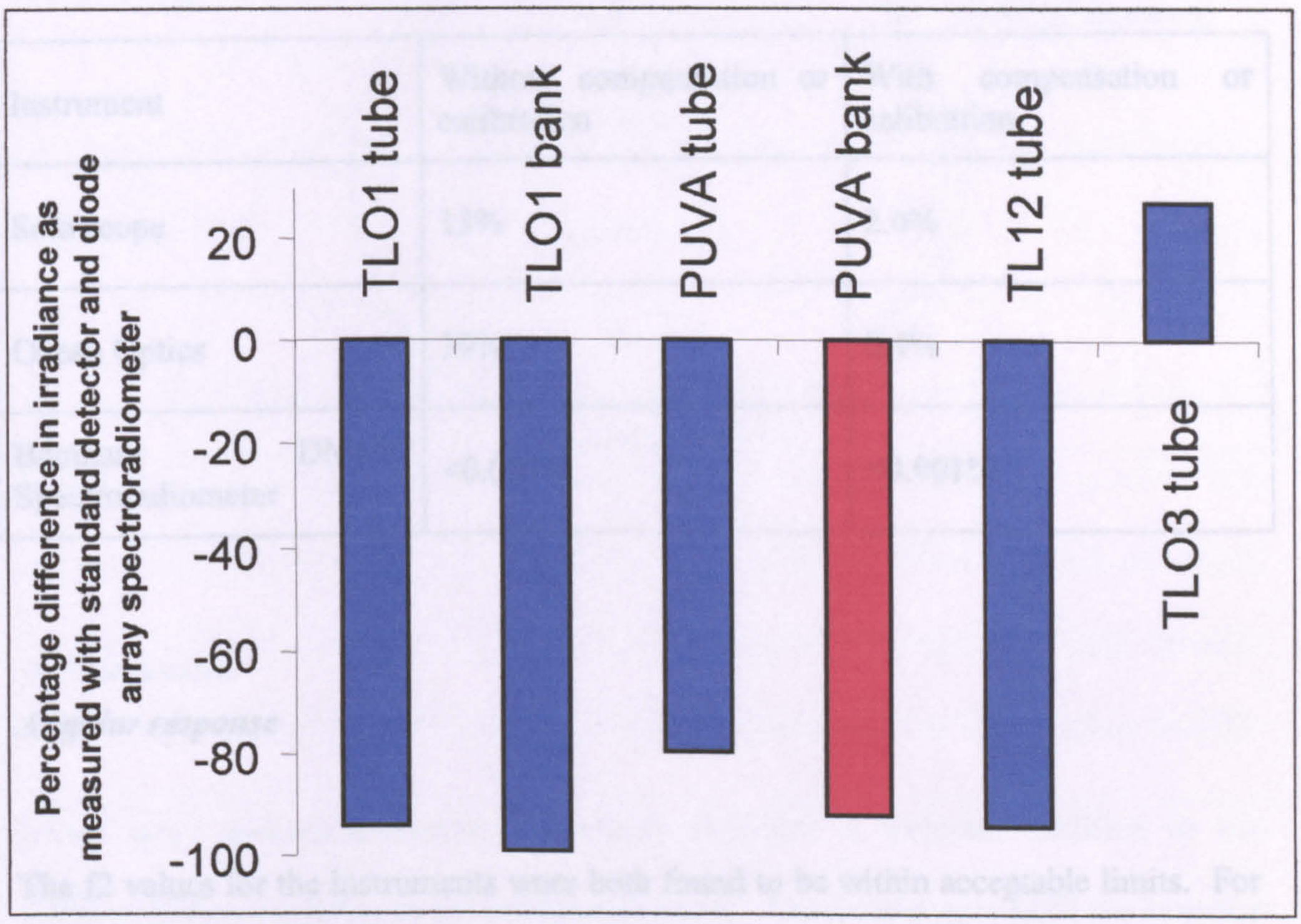


Figure 2.9: Graph to show the differences in measured irradiances when comparing custom calibrated Sola Scope with Bentham spectroradiometer and, in the case of the cabinets, an IL1400 radiometer. TLO1 values from integrated irradiance 280-315 nm. PUVA and UVA1 from integrated irradiance 315-400 nm.



Measurements of phototherapy sources using the Ocean Optics showed the instrument underestimated the irradiance in all but the cases of a blue light source (figure 2.10). The recorded spectra were very noisy at low wavelengths and this fact, combined with the low responsivity of the instrument at low wavelengths, produced errors of the magnitudes seen and illustrates that this instrument is not at present sensitive enough to be used for UV radiation dosimetry.

Figure 2.10: Graph to show the differences in measured irradiances when comparing calibrated Ocean Optics with Bentham spectroradiometer and, in the case of the PUVA bank, an IL1400 radiometer. TLO1 and TL12 values from the integrated irradiance 280-315 nm. PUVA from the integrated irradiance 315-400 nm. TLO3 from the integrated irradiance 400-500 nm.



Stray light performance

The stray light levels with both instruments were significant, as was expected. The method of correcting for stray light with the orange filter reduced the stray light significantly. Table 2 shows the stray light ratios if the signal at 250 nm (no irradiance, [24]) is compared with that at 430 nm (maximum irradiance). The levels are

significantly reduced when the Sola Scope's stray light compensation method is used and when the calibration is applied to the Ocean Optics raw signal.

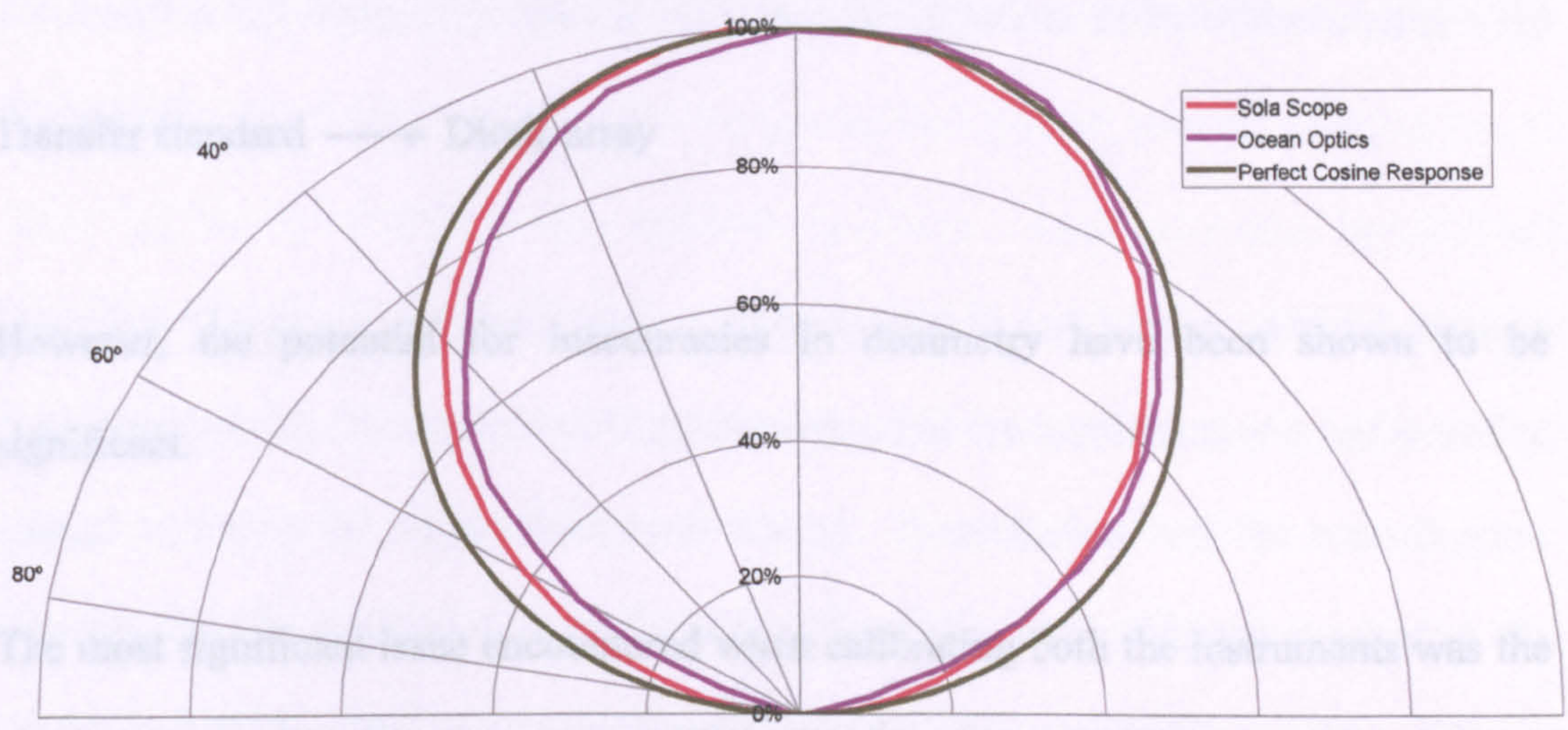
Table 2: Stray light ratios from the diode array instruments. The percentage value expressed is the ratio of the signal at 250 nm to that at 430 nm.

Instrument	Without compensation or calibration	With compensation or calibration
Sola scope	13%	2.0%
Ocean Optics	39%	0.4%
Bentham DM150 Spectroradiometer	<0.001%	<0.001%

Angular response

The f2 values for the instruments were both found to be within acceptable limits. For the Sola Scope the value was 5.1% in the plane parallel to its grating and 6.7% in the plane perpendicular to its grating (+/-60°). This provides an overall f2 value of 5.9% (+/-60°). For the Ocean Optics the value was 7.8% (+/-60°). The cosine responses can also be represented as a polar plot (figure 2.11).

Figure 2.11: Polar plot to represent spatially the cosine responses (as a percentage of the maximum) of the Ocean Optics and Sola Scope at incident radiation angles from 90° to –90°.



4. Discussion

Diode array spectroradiometers potentially represent a welcome addition to the instrumentation available to the medical physicist. The instruments fulfil the majority of the requirements of radiometers for use in dosimetry- as identified in section 2. The instruments are portable, easy to use and acquiring spectral data is speedy compared with traditional spectroradiometry. The cost of the instruments may allow centres to acquire spectral measuring capabilities where spectroradiometers were outside of their means.

This type of instrument also allows for a shorter calibration chain than exists with filtered radiometers. Because radiometers do not collect any spectral information, a

separate calibration for each phototherapy source to be measured is needed. Diode array instruments negate the need for this step:

Transfer standard ⟶ Bentham $\xrightarrow{phototherapy}$ Filtered radiometer

Transfer standard ⟶ Diode array

However, the potential for inaccuracies in dosimetry have been shown to be significant.

The most significant issue encountered when calibrating both the instruments was the sensitivity of the detector arrays. The transfer standards routinely used in the department are a 100W, frosted glass, tungsten lamp for UVA radiation measurements (315-400 nm) and a 30 W deuterium discharge lamp for UVB (280-315 nm). Neither diode array instrument proved to have sufficient sensitivity to detect these transfer standards.

These sources are used as transfer standards in order to comply with CIE guidelines [16], which recommend that detectors be calibrated against sources with a known spectral intensity and distribution that is similar or the same as the source to be measured. The 1 kW FEL lamp employed for the calibrations was not ideal for UVB measurements but was the only source available that had sufficient signal to be detected by the instruments.

This lack of sensitivity presented a challenge during the angular response measurements. The deuterium discharge lamp is also a good approximation of a point source, and would normally be used for measuring the cosine response of any radiometer [21]. A xenon arc lamp was used because it had sufficient signal to be detected but did allow us to demonstrate that the f2 values of both instruments were acceptable.

The Sola Scope is supplied with a manufacturer's calibration derived from a deuterium source. Hence, it was very surprising that the instrument was not sensitive enough to detect the output from such a lamp. Consultation with the manufacturer revealed that the calibration is performed without the cosine diffuser attached to the sensor and final calibration is derived by coupling the transmittance of the diffuser and the responsivity of the detector array [25]. It is possible that uncertainties inherent in this calibration method lead to the error seen in the supplied calibration and subsequent errors when measuring phototherapy sources (see figures 2.7 & 2.8). Calibration of the intact instrument using the 1 kW FEL lamp was sufficient to reduce the error in the readings from the instrument to within 12% (figure 2.9). A calibration method such as this, keeping the instrument intact, would certainly be necessary for any clinical application. Errors of the magnitude that the supplied calibration was producing, could certainly lead to patients receiving the wrong dose.

The UV responsivity of the Ocean Optics meant that even using the 1 kW calibration source, recorded spectra were of a similar signal level to the noise inherent in the instrument. This meant that all the phototherapy sources measured were too low in intensity to give a discernable spectral output, and it was only with a largely visible

source that the signal was large enough to exceed noise levels (TL03). This occurred despite the instrument supposedly being optimised for UV and visible wavelengths. This instrument could have potential in the clinical environment if its quantum efficiency in the UV were increased substantially. The calibration method for this instrument should also be revised. Very few light sources, and certainly not phototherapy sources, match the black body emission spectral profile. Convolution of some calibration source to this emission spectrum, based on colour temperature immediately introduces error into the calibration. The method that was used with the 1 kW FEL lamp would certainly be more satisfactory if the sensitivity issue is addressed.

As expected, the stray light levels in measurements from these instruments were high. It has been shown, however, that it is possible to compensate for the stray light by one of two methods. An orange glass filter can be used to find the stray light profile for any source being measured and the 'profile' then subtracted from any final spectrum. Alternatively the stray light can be calibrated out by including stray light in any spectrum of a calibration source and therefore including stray light in the sensitivity factor (SF_λ). The first method is the most favourable because it takes into account different spectral profiles of any source, although it requires two scans of any source to be made which can have potential exposure risks when measuring phototherapy sources.

The Sola Scope instrument currently shows significant potential for use in a clinical environment. The calibration supplied by the manufacturer was unsatisfactory but this could be improved using a high output source and stray light correction. With

these modifications in place the errors in measuring phototherapy sources were calculated as being up to 12%, in line with errors inherent in filtered radiometer readings.

The Ocean Optics device should have its sensitivity increased and its calibration protocol re-written before it should be considered for dosimetry.

Although there is potential benefit associated with this type of instrument, caution should be advised in its use within a clinical environment. Calibration issues surrounding this type of instrument have not yet been adequately addressed by manufactures to advocate the replacement of the filtered radiometer in the photomedicine clinic with a device such as this. There would be particular concern over the use of the device like this by non-specialist staff, since errors can be considerable. An erroneous reading of the magnitudes shown in this evaluation could easily lead to a patient being burned.

This type of technology is also beginning to have an impact on different areas of UV metrology. The Finnish Radiation Protection Authority (STUK) developed a method of correcting stray light and noise in a different Ocean Optics model for sunbed hazard assessment. Calibrating using a 1 kW FEL lamp provided favourable results [26]. Coupled with a Czerny-Turner monochromator, diode array systems are being used for SUV monitoring [27,28]. It is also encouraging to see National Measurement Institutes (NMI's) putting effort into methods of calibrating diode array systems in order to correct and guarantee measurements. For instance, NIST has developed a method of compensating for stray light and transferring the calibration of

a tungsten halogen lamp to a diode array spectroradiometer [15]. This is also similar to the method I piloted in 2002.

5. Conclusions

The evaluation performed shows that diode array spectroradiometers may have significant potential for use in dosimetry because they have most of the properties required for dosimetry instruments. However, the potential for errors with this type of instrument are also significant.

The length of the calibration chain, from national standard to meter for dosimetry is shorter with spectral instruments, but the accuracy of measurements should be monitored carefully. There is significant potential for errors in dosimetry above the 10% level. Such errors may be due to an inappropriate choice of detector. Particularly with filtered radiometers, the properties of the detector must be understood or doses may be under (or over) estimated. Trained staff are also invaluable for ensuring accurate dosimetry. This is particularly true with diode array spectroradiometers. The lack of sensitivity that the instruments evaluated displayed would lead to serious errors in dosimetry if an untrained member of staff did not recognise the problem.

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Chapter 3

Measurement of skin response for hazard assessment

Response of normal and abnormal (CAD and SU) skin to polychromatic light

Summary

In order to test the assumption that different wavelengths are additive in producing erythema, seven volunteers were recruited, during the period from 2002 to 2005, to undergo monochromator phototesting and then testing with polychromatic sources. The hypothesis of linear responses has been extrapolated to photosensitive skin and thus, during the same period, 19 of the most sensitive patients suffering from solar urticaria or chronic actinic dermatitis, and attending the clinic for routine testing, were tested for their response to polychromatic light in addition to their normal phototesting.

In normal volunteers the MEDs at phototest wavelengths and doses at which they would experience erythema (based on their lowest MED) from polychromatic lights were calculated using the erythemal action spectrum. The actual responses are compared with those expected.

For patients: individual action spectra were constructed from monochromator testing results, and effective irradiances for polychromatic sources were calculated from these action spectra. A dose at which a patient would react was predicted using the total effective irradiance of the source and the patient's lowest MUD and/or MED.

Patients were then phototested with these sources, using a geometric dose series and the erythemal or urticarial response was assessed and compared to the predicted reaction.

Within the limits of this experiment, the results indicate that neither erythema nor these disorders respond in a linearly additive manner to polychromatic radiation. This contradicts assumptions made in many photobiological publications.

1. Introduction

Individuals with photosensitive skin can face a hampered lifestyle due to their inability to tolerate the wavelengths of light to which they are sensitive. The various conditions leading to photosensitivity and their impacts on the lives of sufferers are discussed in chapter 1. Management of these conditions (discussed in chapter 4) represents a clinical challenge that is further complicated by the fact that no one causal factor has been identified for any of the idiopathic photodermatoses.

The Scottish Photobiology Unit at Ninewells Hospital in Dundee is a national centre for research on light associated skin disorders [1] and a national tertiary referral centre for testing, diagnosis and treatment of suspected photosensitivity. Patients referred to the centre have detailed histories taken, are examined and then undergo testing in order to rule out photosensitivity or to define the condition and then decide on appropriate treatment.

Phototesting is used as the objective basis for diagnosis of photosensitivity [2,3]. Narrow band radiation, of a known intensity, is shone onto a patient's back. A range

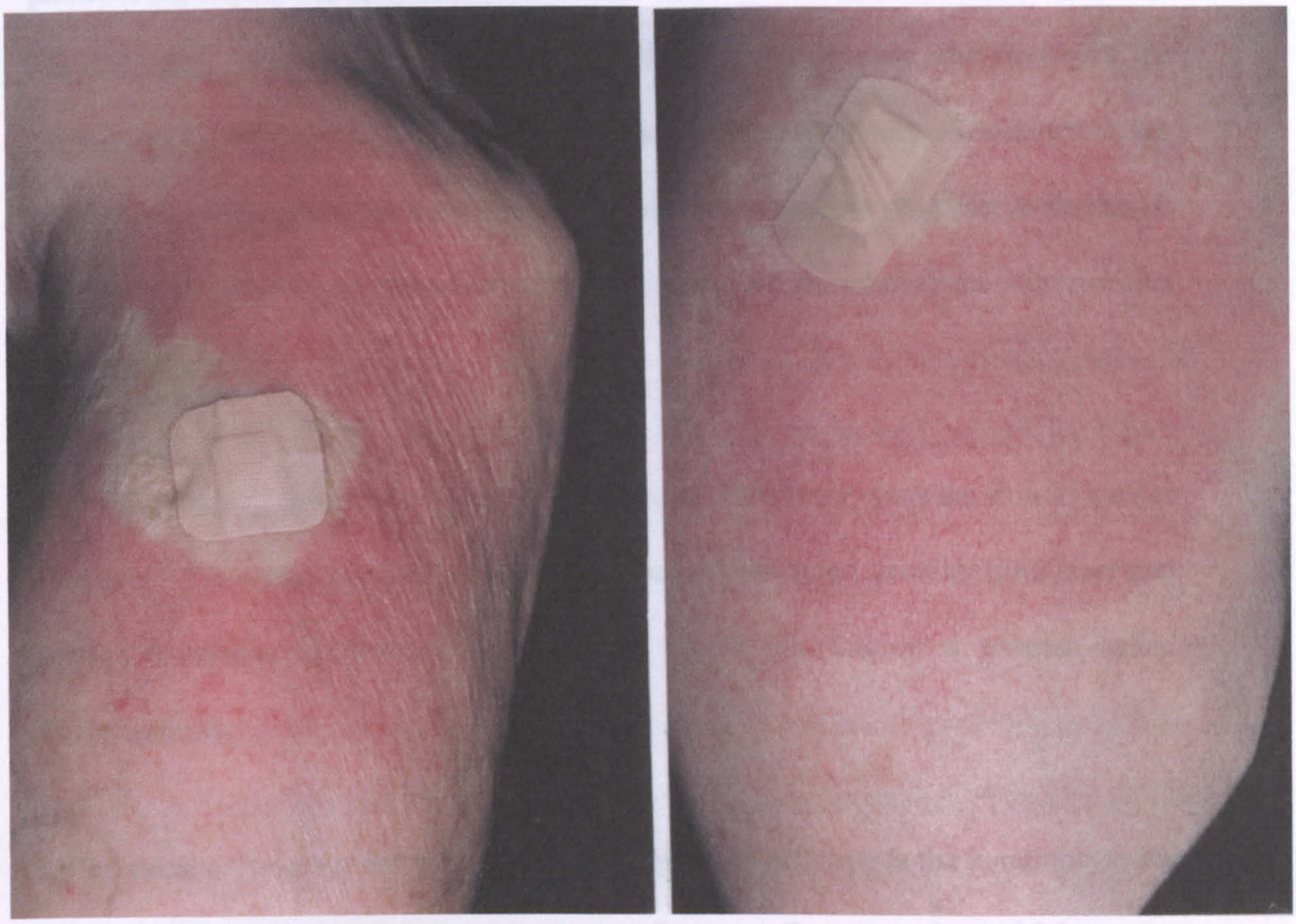
of doses and wavelengths allows the tester to define the minimum amount of radiation necessary to provoke a response at each wavelength. The British Photodermatology Group has published guidance on Phototesting [4]. The results of phototesting are said to be able to be used to construct an action spectrum for a patient's sensitivity [5-7].

Repeated phototesting also provides useful information regarding the progress of disease and any changes in the involved wavelengths [8]. It can also be used as an objective means of assessing the improvement in a condition [9].

Some photosensitive skin disorders give normal results on phototesting (namely AP, PLE [10] and HV) and hence provocation testing is indicated. This type of testing involves irradiating a large area of skin with different light sources. The provocation sources may be UVA or UVB or broad spectrum, such as solar simulated radiation. This type of testing will reveal any multi-waveband interactions that provoke a reaction that is not seen with phototesting.

In the most sensitive individuals a flare of the skin can be a serious, even life threatening problem [11]. There are reports in the literature of severe phototoxic burns in patients with porphyria when they were hospitalised for surgical procedures [12,13]. While risks in situations such as this can be minimised with careful planning and use of appropriate filters [14], this is not always possible in the case of emergency surgery [12] and/or lack of knowledge of a patient's sensitivity or action spectrum. Indeed, Mr Doherty (the case study in chapter 1) suffered a flare of his skin during a routine biopsy in the dermatology clinic at Ninewells (see figure 3.1).

Figure 3.1 Urticaria induced by theatre lights



Clearly any such response is undesirable. The increasing use of PDT as a treatment modality for tumours at various body sites goes hand in hand with the problem of persistent photosensitivity that accompanies the use of systemic photosensitisers [15]. These patients can spend a considerable amount of time in theatre while tumours are irradiated and have to be protected from exposure to sources such as theatre lights. Hence, a prediction of the tolerable levels of exposure would be a useful tool not only for those with idiopathic photodermatoses but also for those photosensitised for PDT. Appendix 3.1 shows measurements made of the spectra of sources encountered in an operating theatre and a patient being irradiated.

Chronic actinic dermatitis [16,17] and solar urticaria are two conditions in which phototesting is particularly useful. The wavelengths involved in SU can be up to 700 nm and often more than 400 nm in CAD. In order to develop new strategies for managing and treating photosensitive skin disease, it is necessary to understand the fundamental photochemical mechanisms of the disease process. In order to do this, it is helpful to consider the structure of normal skin, and the photochemical reactions that may occur [18].

The outer layer of the skin is the stratum corneum. This layer gives the skin its barrier function [19]. It is made up of a metabolically active structured lamellar lipid layer and mature keratinocytes (termed corneocytes), which are lost in a process called desquamation.

Underneath is the outer cellular epidermis. The main cell type is the keratinocyte but there are also melanocytes and Langerhans cells in smaller proportions. Melanocytes synthesise melanins that are transported as larger particles (melanosomes) to keratinocytes where they are degraded into smaller particles that are then discarded during desquamation. Langerhans cells have an antigen presenting function and are thus part of the systemic immune system. UVR has a direct effect on the number, morphology and functionality of Langerhans cells and therefore has an immunosuppressive effect [20*].

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* For full reviews of the immunosuppressive effects of UVR see Clydesdale *et al* [21] and Schwartz [22].

Below the outer cellular epidermis is the basal layer where keratinocytes proliferate by division. The basal layer sits on the basement membrane which is a largely non-cellular dermis containing structural proteins such as collagen and elastin.

Normal skin exhibits an erythemal response when the minimum erythema dose (MED) is exceeded. This is a cutaneous inflammation characterised by the formation of sunburn cells that appear as early as 30 minutes after exposure and are at a maximum 24 hours following exposure. The sunburn cell originates from damaged keratinocytes. There are a number of different mediators for this damage, including histamine. Following erythema, which fades in 72-120 hours, there is an increase in skin pigmentation desquamation and thickening of the epidermis [23].

Any biological response is actually initiated by the absorption of ultraviolet or visible radiation by chromophores in the skin. The term chromophores actually relates to the unsaturated bonds in conjugated molecules, as it is these bonds that are responsible for absorption properties. However, the term is commonly used to describe the whole molecule [18] and this trend will be followed in this chapter. There are two mechanisms of initiating a biological response. Firstly, in a uni-molecular reaction the chromophore may be directly altered by the absorption of photons. Secondly, in a bi-molecular process, there may be damage to bio-molecules initiated by active oxygen species produced when endogenous chromophores absorb radiation.

Endogenous chromophores in human skin include keratin proteins, haemoglobin, pophyrins, carotene, nucleic acids, melanins, lipoprotein, peptide bonds and aromatic amino acids [11]. The absorption spectra of individual chromophores can be determined

in vitro by absorption spectroscopy. Many of these chromophores have poorly understood absorption and scattering properties. However, the complexity of the structure of the skin means that even if the absorption spectra of separate chromophores are known, *in vivo*, the optical properties of tissue, the fact that absorption spectra overlap and interactions can occur with other bio-molecules means that the action spectra of human skin is not predictable on the basis of the chromophores contained therein [18].

DNA is a significant chromophore and its absorption characteristics have been well-defined [18]. Pyrimidine bases are the most sensitive and are modified by either direct absorption of photons or by free radicals generated in bi-molecular reactions. These modifications generate photolesions, the most important being cyclobutane and pyrimidine dimers and pyrimidone photoproducts [20]. Normal enzymatic function will repair this damage unless there is excessive damage in which case mutations will appear in the DNA. Indeed, 80% of sun induced human skin cancers contain P53 mutations at dipyrimidine sites [24]. DNA is thought to be the chromophore for erythema as pyrimidine dimer is an important causative lesion in sunburn [18].

The absorption and scattering properties of urocanic acid (UCA) have also been well-defined [18]. It naturally occurs as the *trans* isomer but UV irradiation can cause *trans* to *cis* photoisomerization. *Cis*-UCA thought to be a mediator for suppression of delayed–type hypersensitivity, thus effectively having an immunosuppressive effect.

The absorption properties of the melanin group of pigments are poorly understood [18]. Melanins are known to scatter and absorb UVR. Exposure of the skin to UVR stimulates melanogenesis, which may be associated with photosensitisation and/or the

development of malignant melanoma (see Diffey *et al* [25], Setlow *et al* [26] and Mackie [27]). Exposure to UVA and visible light leads to the transient effect of immediate pigment darkening which is believed to be due to photo-oxidation of melanins [18]. Kollias *et al* [28] describe the photochemistry of melanin and its photoprotective effects.

The erythemal action spectrum is well-defined and shows that UVB is three to four times more effective in causing erythema than UVA [29]. The functions representing the action spectrum are shown in equations 4.1 to 4.3.

$$\varepsilon(\lambda) = 1.0 \qquad 250 \leq \lambda \leq 298 \text{ nm} \qquad \textbf{Equation 3.1}$$

$$\varepsilon(\lambda) = 10^{0.094(298-\lambda)} \qquad 298 < \lambda \leq 328 \text{ nm} \qquad \textbf{Equation 3.2}$$

$$\varepsilon(\lambda) = 10^{0.015(139-\lambda)} \qquad 328 < \lambda \leq 400 \text{ nm} \qquad \textbf{Equation 3.3}$$

The action spectrum is shown in figure 3.2 and has been confirmed with laser-based studies [30]. This action spectrum can be used to calculate an erythemal effective dose of any source (e.g. [14]), using the spectral irradiance of the source:

$$ED = \sum I_\lambda \varepsilon_\lambda \Delta\lambda \qquad \textbf{Equation 3.4}$$

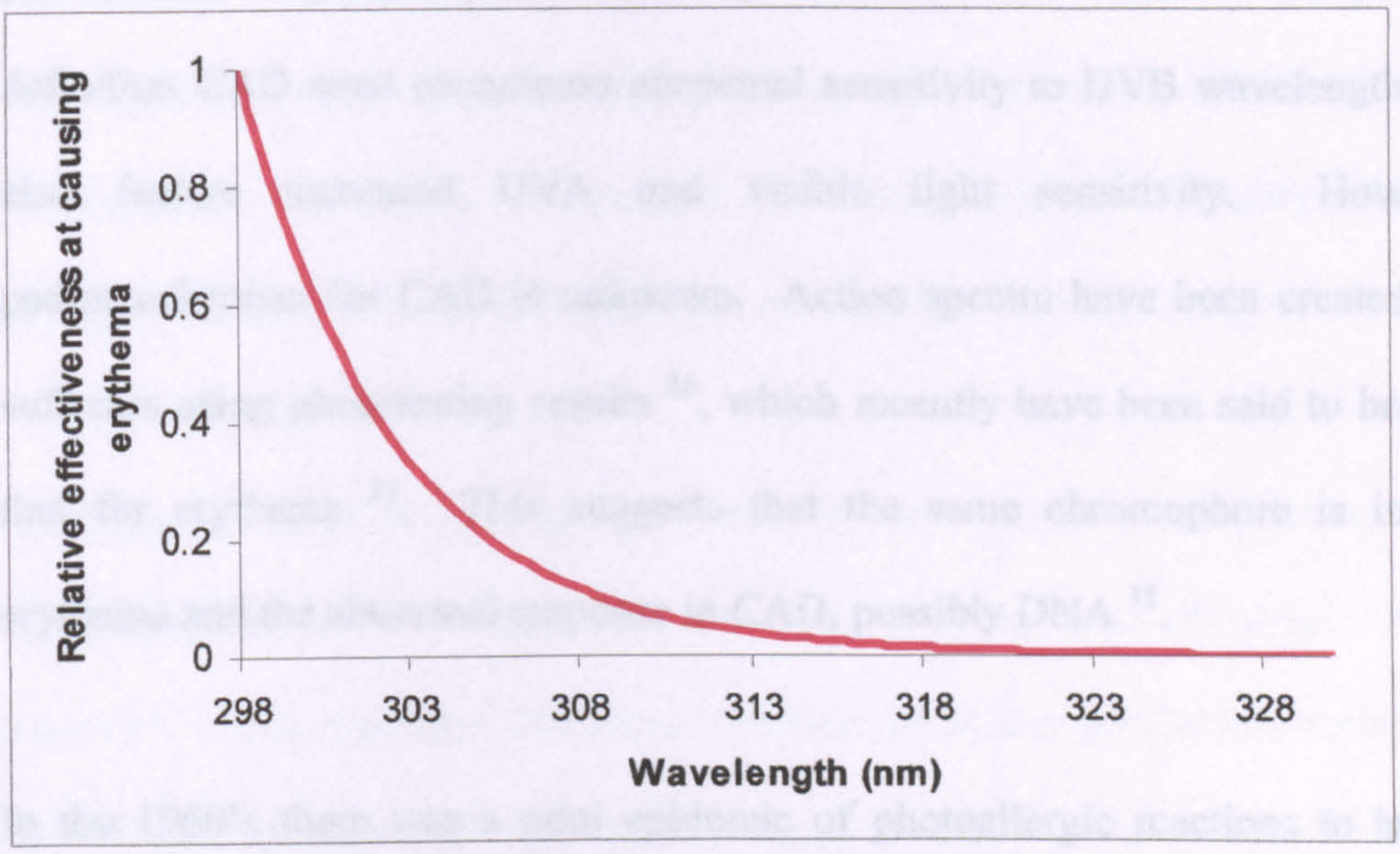
Where:

ED is effective dose

ε_λ is the action spectrum value at wavelength λ

I_λ is the spectral irradiance of the source at wavelength λ

Figure 3.2: Erythemal action spectrum [29]



If a person's minimum erythema dose (MED)* is known then the time to erythema from any source can be calculated once the erythemal action spectrum has been applied to the source's spectral irradiance. This technique also allows the relative effectiveness in eliciting erythema to be compared for different sources. Inherent in the use of this equation is the assumption that different wavelengths are linearly additive. That is that there are no synergistic or protective interactions between different wavelengths and the incorporation of a multiplication factor (action spectrum) allows the effective irradiance of a source to be calculated. This has been said to be true for erythema in normal skin, derived from tests with phototest equipment [31,32]. This equipment irradiates with narrow band radiation and therefore does not test the integrity of the action spectrum for polychromatic radiation.

* The dose required to produce just perceptible erythema (redness)

Chronic actinic dermatitis was proposed in 1979 [33] and widely accepted in 1990 as a unifying concept for the previously separate syndromes of persistent light reactivity, photosensitive eczema, photosensitivity dermatitis and actinic reticuloid [34]. By definition CAD *must* encompass abnormal sensitivity to UVB wavelengths but may also feature increased UVA and visible light sensitivity. However, the pathomechanism for CAD is unknown. Action spectra have been created for CAD sufferers using phototesting results [16], which recently have been said to be similar to that for erythema [35]. This suggests that the same chromophore is involved in erythema and the abnormal response in CAD, possibly DNA [18].

In the 1960's there was a mini epidemic of photoallergic reactions to halogenated salicylanilides used in soaps and hair toiletries [11,23]. Photoallergic contact dermatitis reactions are rare because the individuals that suffer must have a specifically altered immunologic background [23]. These reactions are mediated by lymphocyes and characterized as delayed hypersensitivity reactions. Photoallergic reactions need radiation to form a complete antigen, in contrast to allergic contact dermatitis where the antigen is present already. The events that form a complete antigen are not well-understood [11].

Many of the patients that suffered from photoallergic contact dermatitis to halogenated salicylanilides went on to develop persistent light reaction [23]- eczematous dermatitis when exposed to radiation, even if the photosensitiser is no longer present[11]. Hence one early theory of CAD pathogenesis was that photoallergic chemicals persist in the skin [17]. The action spectrum of any such photosensitiser would have to include UVB, A and visible radiation and as yet no such compound has

been found [36]. A more complex hypothesis is that the development of CAD occurs after an episode of photoallergy. This then causes alteration and transformation of a skin chromopore that consequently develops into an endogenous antigen that can perpetually react with specific wavelengths to induce a chronic inflammatory process [11]. However, only up to 75% patients have associated contact and/or photocontact allergy [17] and hence these theories do not account for the whole story.

Certainly the pathophysiology of CAD is only partially understood. Cellular hypersensitivity to UVA has also been shown in cultured fibroblasts from CAD patients [37]. It is suggested that there is deficiency in the cellular mechanisms dealing with oxygen radicals leading to excessive cell damage on exposure to UVA [37]. This, however, does not explain the increased sensitivity to UVB and/or visible wavelengths.

The histologic findings in CAD bear a resemblance to persistent allergic contact dermatitis and are compatible with delayed type hypersensitivity response [23,36]. There have been several evidence based suggestions made that CAD is a T cell mediated response compatible with type 4 immune response [17,36]. The prospective chromophore involved in this process remains unidentified [36].

It may be many years before the causal factor(s) for CAD is known and the mechanisms involved are elucidated. It seems likely that this condition represents a spectrum of disorders [38] resulting from heightened immune reactivity [17] whereby a weak, endogenous photoallergen that is present at all times in all people, is recognised

as a photoallergen in patients with CAD [36]. The type 4 response to UV light and associated contact allergies would therefore represent immune dysregulation [17].

More research into the etiology of this disabling condition is needed to help clinicians manage and treat sufferers. This is an uncommon condition, affecting 1:6000 people in Tayside with men accounting for 78 to 90 % of sufferers [36]. Patch and photopatch testing should always be performed in cases of suspected CAD in order to exclude or reveal any associated contact dermatitis and/or photoallergic contact dermatitis [39].

Solar urticaria is a rare disorder, affecting 3.1 per 100,000 people in Tayside [17]. The wavelengths involved in the condition include UVA, B and visible radiation [40] and occasionally infrared radiation [41]. The action spectra as derived from monochromator testing are often broad [17] and can change in individual patients over a period of years [42]. The interactions of wavelengths in solar urticaria are known to be complex and in some subjects feature augmentation and inhibition effects [43,44]. The mechanisms involved in these interactions are not understood [41]. Knowledge regarding these effects in patients is often based on pre or post-irradiation and not on the simultaneous effects of polychromatic light in comparison to irradiation monochromator phototesting results.

Solar urticaria is an IgE mediated immediate type hypersensitivity reaction [11]. The histological features of the disease are the same as acute urticaria: dermal odema, vasodilation and variable perivascular infiltrate consisting of lymphocyes and eosinophils [11]. The chromophore responsible for this immune response is not known

but may be a normal serum factor in some patients and an abnormal endogenous substance generated in others [41].

It has been proposed that a photoallergen is formed after irradiation in SU [45]. The urticarial response is then triggered when IgE antibodies specific to the photoallergen are generated and bind to mast cells. Further interaction between the IgE mast cell complex and the photoallergen leads to mast cell degranulation and release of inflammatory mediators, including histamine [41].

In précis: phototesting is used for diagnosis, and thought to be useful for constructing an action spectrum in photosensitive skin disease. However, no studies have been published to date that test the assumption that the results of phototesting can be used to construct an action spectrum and an effective irradiance for any light source as is routinely done for erythema.

The use of the erythemal action spectrum to compare erythemal effectiveness of sources is ubiquitous and represents a widely accepted paradigm in photobiology. Its use with polychromatic radiation is accepted although, to my knowledge, there are no publications that test this assumption. Sutherland [46] presents a theoretical interpretation of the effects of polychromatic light and suggests that the linear hypothesis of the erythemal action spectrum can be tested by predicted erythema doses and then testing them with polychromatic sources. He calls the prediction of the effects of polychromatic light a 'central goal' of environmental photobiology.

The ability to predict safe exposure limits for diseased or photosensitised skin would assist in hazard assessment. The safe limits of exposure to theatre lights for patients

having PDT in an operating theatre and the amount of sunlight tolerable by a CAD patient could all be assessed. Furthermore, the hazards posed to patients when photosensitising broad-spectrum antibiotics [47] are a therapeutic necessity could be determined.

In order to test this assumption for erythema and diseased skin, patients and volunteers were recruited to take part in the presented study. Volunteers with normal skin were recruited to be phototested and then tested with polychromatic sources. Also, CAD and SU patients attending the Photobiology Unit for routine testing for photosensitivity were recruited to have some extra provocation testing with broadband sources in order to test the hypothesis that phototesting results can be used to construct an action spectrum in these disorders. This hypothesis assumes that the wavelengths of light provoking reaction in these patients are linearly additive. In SU patients it was expected that this would not be the case due to the likelihood of the existence of inhibition and augmentation spectra. However, this testing may help to understand the interactions of wavelengths of light when irradiating with polychromatic sources.

2. Methods and materials

Phototesting

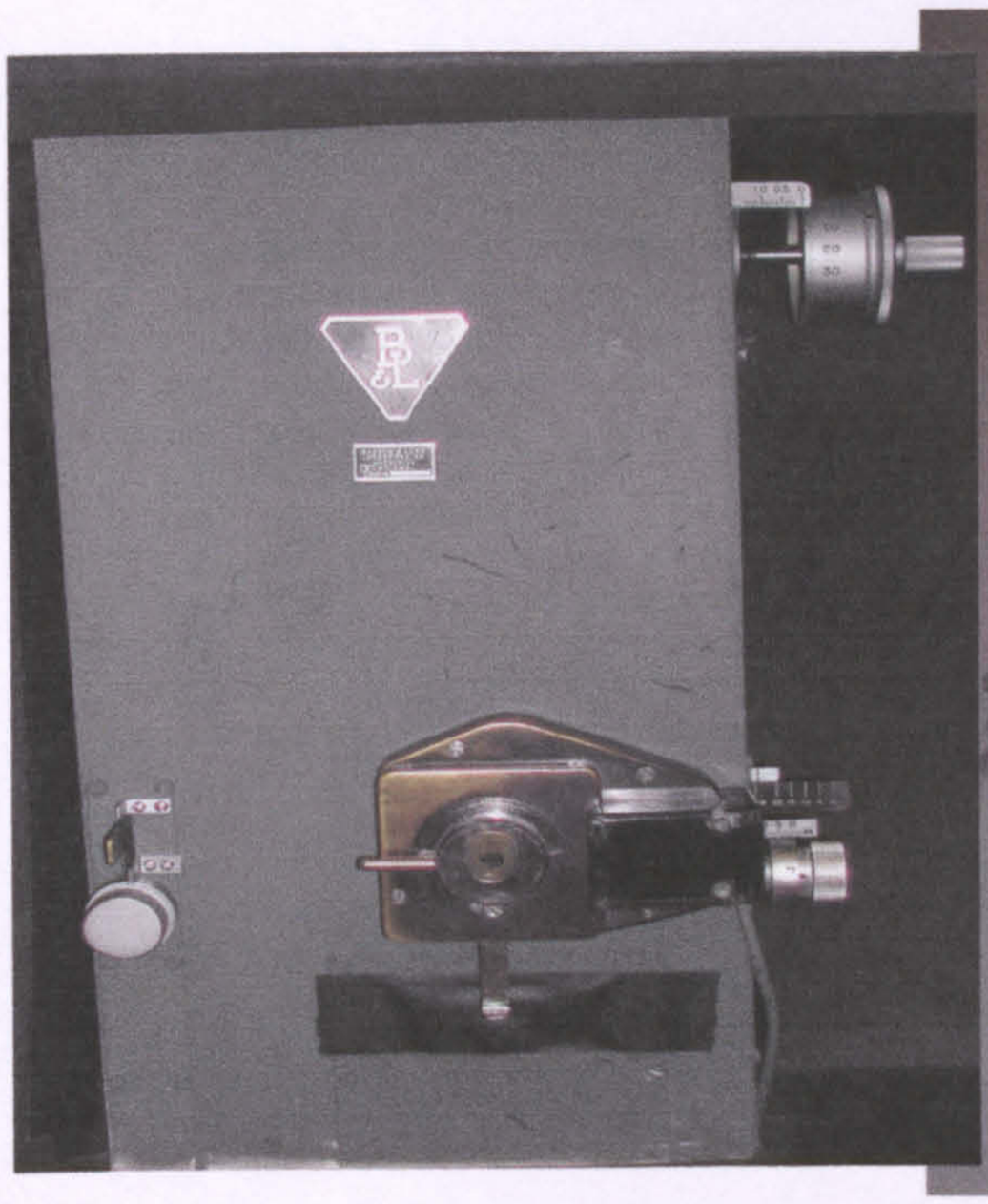
At the Unit, Phototesting is carried out according to BPG guidelines [4] and accepted best practice. The back is used as the phototest site as it is usually the most sensitive area, unlikely to be tanned and gives a uniform response [48]. If there is too much active skin on the back then either another area is chosen, namely the buttocks [49], or the patient is hospitalised until their reaction has been suppressed with topical corticosteroids.

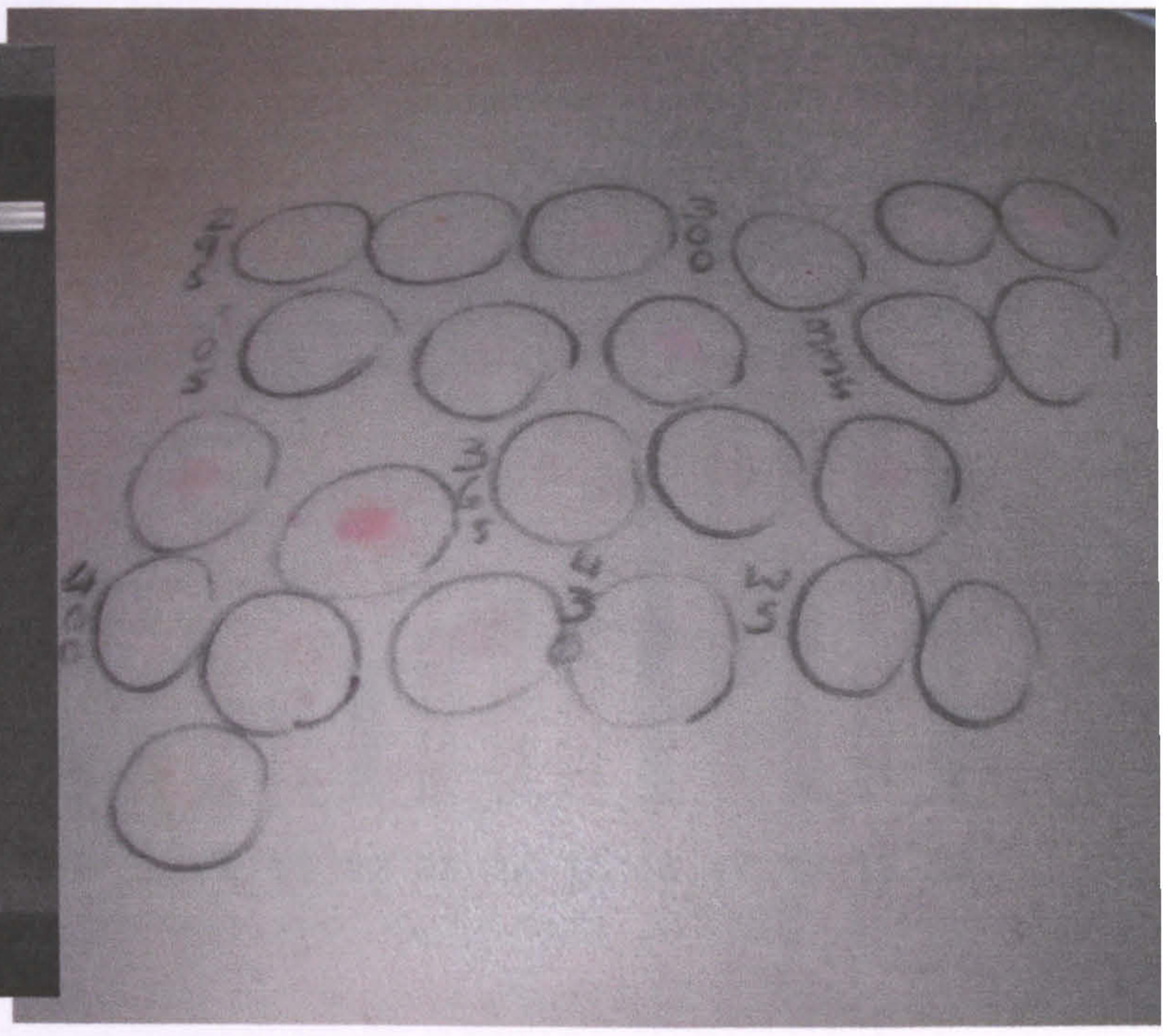
A xenon arc lamp and single grating irradiation monochromator are used (see figure 3.3) with the wavebands and filters listed in table 3.1. The monochromators are aligned with a medium pressure mercury arc lamp and dosimetry is performed prior to each irradiation using thermopiles with calibration traceable to NPL. Thermopiles are wavelength independent detectors [50] and therefore have a flat response across the wavelength range used for phototesting.

Table 3.1 Routinely used phototest wavelengths, wavebands and filters. Lowest normal MED values against which comparisons are made.

Wavelength	FWHM	Filter	Lowest normal MED ($mJcm^{-2}$)
305	5	-	27
335	30	WG305	1800
365	30	WG305	8200
400	30	WG345	47000
430	30	GG375	82000
460	30	GG420	82000
500	30	GG420	82000
600	30	GG420	82000

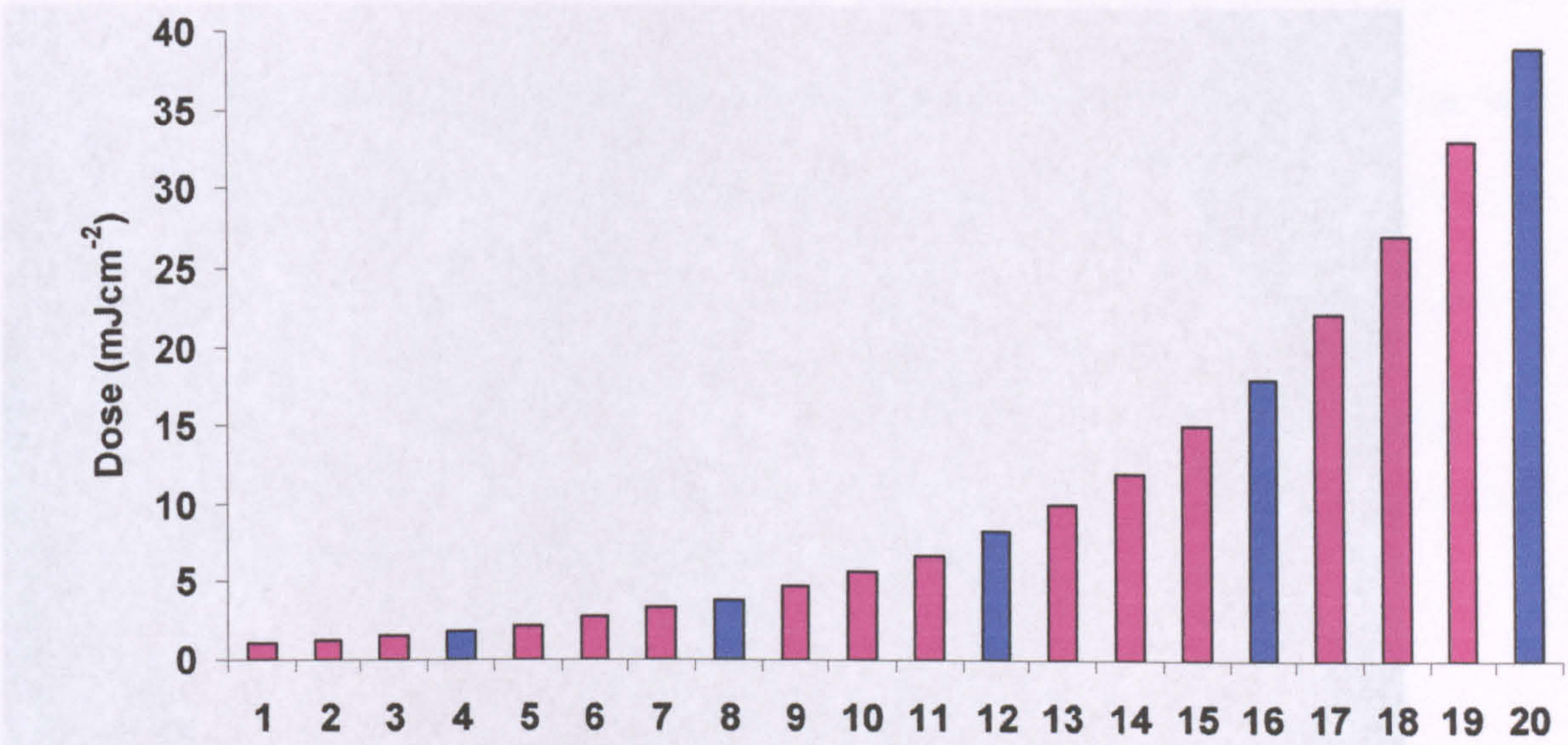
Figure 3.3: Irradiation monochromator testing. The irradiation monochromator (left) and a subject's back, where erythema can clearly be seen from testing at different doses and wavelengths.





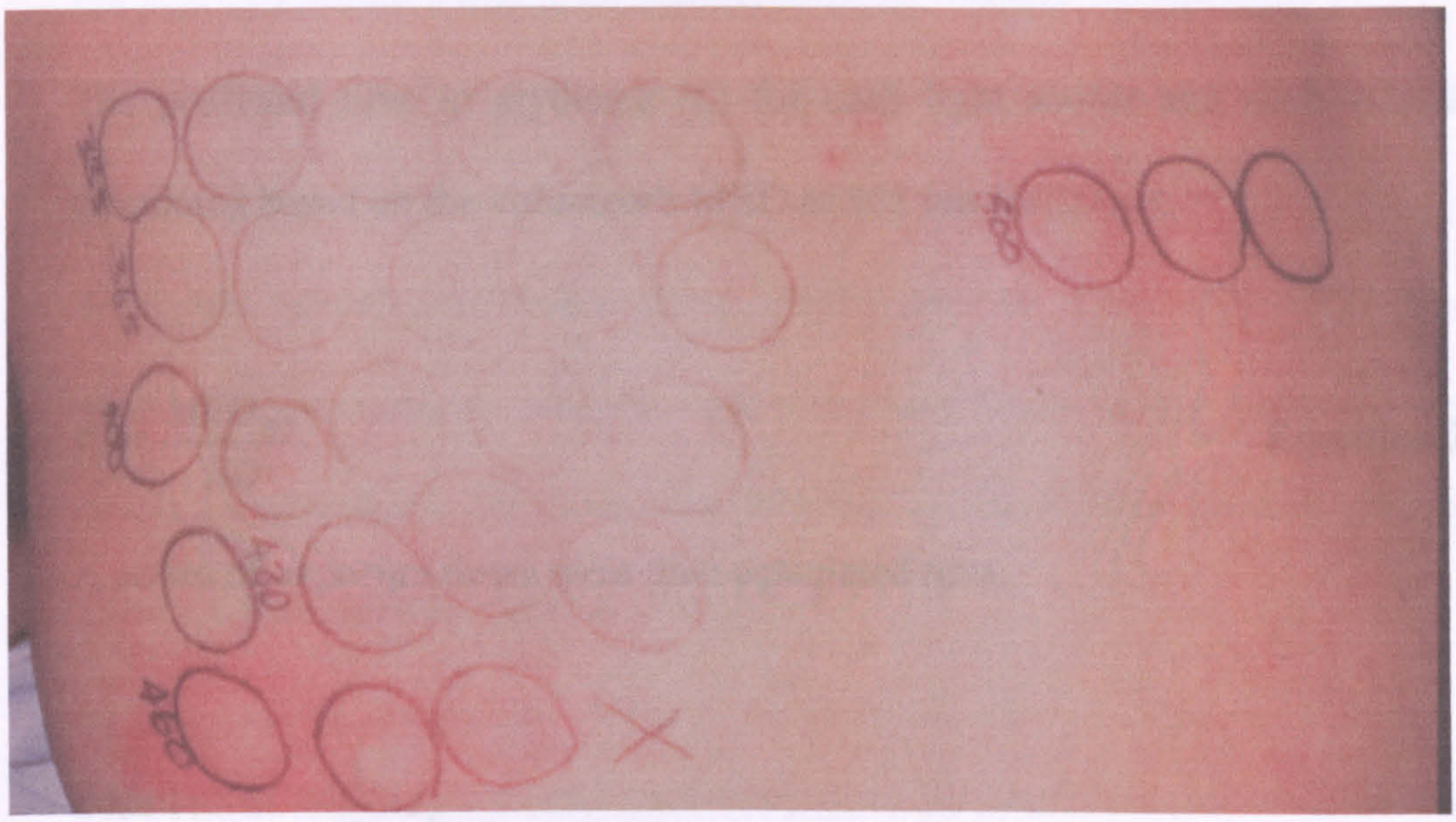
The dose increments used are shown in figure 3.4. The series is geometrical- exposures are increased by a ratio of $\sqrt{2}$ [3]. On the first day of testing, crude dose increments are used. The blue bars in figure 3.4 indicate those doses given at 305 nm (+/-5 nm). These steps include the lowest normal MED at the test wavelengths (see table 3.1) and are designed to 'catch' a patient's MED. Appropriate multiples of the test doses are used e.g. for 335 nm (+/-30 nm) the doses are multiplied by 100. The patient returns 24 hours later for reading of the grades of erythema seen and then fine dose increments (pink on the graph) from the step above where no reaction was seen to the dose below where a reaction was seen are used to define the MED at each phototest wavelength. Barely perceptible erythema is the most reliable threshold for measurement of sensitivity [51] and this is the level taken as the MED.

Figure 3.4 Dose series used for monochromator phototesting. See text for explanation.



If a patient had an urticarial reaction to the radiation then a MUD (minimum urticarial dose) is defined as well as the MED at each test wavelength. Urticarial responses are shown in figure 3.5.

Figure 3.5 Patient with an urticarial response to radiation at 460 and 500 nm



Polychromatic light testing

A variety of sources were used to test the sensitivity of the volunteers. These included a xenon arc solar simulator, blue and UVA light provocation source, TL01 source, PUVA source, a portable theatre light and an UVA1 source. The spectra of these sources were measured using the department's bench based spectroradiometer (Bentham DM150, see chapter 1).

Normal subjects

From November 2002 to April 2005, seven healthy volunteers were recruited from among staff and family at the Photobiology Unit to be phototested as per the method described above.

The erythemal action spectrum was extrapolated to 500 nm [31] and then normalised to 305 nm as this is the first phototest wavelength. Each light source was weighted, in 1

nm steps, according to this spectrum and the total erythemal effective dose (*ED*) between 305 and 500 nm was calculated according to equation 3.7.

The predicted time to erythema (t_x) for each light source and each volunteer was calculated based on the volunteer's MED at 305 nm (MED_{305}).

$$t_x = \frac{MED_{305}}{ED} \qquad \textbf{Equation 3.5}$$

A series of exposure times were then calculated thus:

dose 1: $\frac{1}{2} \times t_x$

dose 2: $\frac{1}{\sqrt{2}} \times t_x$

dose 3: t_x

dose 4: $\sqrt{2} \times t_x$

dose 5: $2 \times t_x$

Hence the maximum exposure was twice the predicted reaction time. In practice many of the exposure time series calculated were rather long and in consultation with experienced staff and in order not to burn volunteers, the same dose series as used in phototesting (with appropriate multiplication factor) was used in order to 'catch' the MED with each source. Sources were chosen according to the time that the volunteer had available and their willingness to tolerate persistent pigmentation. During irradiations appropriate protective sheeting and goggles were used.

The volunteer's responses were assessed at 24 hours after irradiation. As the perception of MED has been argued to be subjective [52], an attempt was made to exclude this with the use of an erythema meter [53] and a chromameter [54,55]. However, the readings were inconsistent because excess pressure causes the skin to blanche. Thus, slight differences in the pressure applied to the skin with either meter leads to unreliable results and hence these results are not presented. An experienced technician's assessment, made by eye, was found to give a more accurate assessment of the MED. Hence the study was 'blinded' as the technicians had not been made aware of the expected reaction times.

Theoretical MED's were also calculated from the erythemal action spectrum. These results were compared with the actual MED's given from phototesting results.

Abnormal subjects

Patients were deemed to be suitable for the study if they

1. Were return patients- so that a diagnosis already existed
2. Attended the clinic as in patients- as they were kept longer than normal and so that inconvenience to the patient was minimised
3. Were suffering from solar urticaria or chronic actinic dermatitis
4. Were happy to volunteer for some extra testing
5. Had enough space on their back for extra testing
6. Were not taking any antihistamines on the day of testing (for this study) that they had not been taking during their phototesting. This effectively ruled out a lot of potential volunteers as antihistamines were often given and repeat testing undertaken on the following days in order to assess the efficacy of antihistamines for that patient.

19 patients were recruited during the period from November 2002 to April 2005. Results from their phototesting were used to construct an action spectrum for each patient. This was achieved by linear interpolation between the phototest points giving a value for the expected MED at each wavelength (see equation 3.6).

$$MED_{\lambda} = m\lambda + c \qquad \textbf{Equation 3.6}$$

where MED is the MED at wavelength λ

m is the gradient of the line

c is the intercept on the y axis

This data was tabulated and divided by the patients' minimum measured MED to give a weighting function (σ) (equivalent to ε) at each wavelength (λ). The spectral irradiances of the light sources were then used to calculate an effective irradiance (I_x) for each source (equivalent to *ED*), thus:

$$I_x = \sum_{305}^{600} I_{\lambda}\sigma_{\lambda}\Delta\lambda \qquad \textbf{Equation 3.7}$$

Where:

I_{λ} is the spectral irradiance of the lamp of interest at wavelength λ

$\sigma_{(\lambda)}$ is a weighting function calculated from the patient's specific action spectrum at wavelength λ

The predicted time to erythema was calculated and revised as for the normal subjects. Irradiation times > 40 minutes were regarded as impractical. Sources were chosen according to the time that the patient was willing to sit for and the space available on the back. Suitable protective shielding and goggles were used during irradiations as with the normal subjects.

The action spectra of the patients with solar urticaria were treated separately. Two spectra were created for these patients: one from their MED's from the monchromator results and one from their MUD's from the monchromator testing. The erythemal effective irradiance of the test sources was calculated as detailed above and then the same process was repeated for the urticarial effective irradiance of the test sources. Hence there are two sets of data, the expected time to erythema and the expected time to urticaria. If urticaria was seen within the doses given then the dose series was discontinued.

Readings were made by experienced technicians at 24 hours for erythemal responses and within 20 minutes for urticarial responses as per the normal subjects.

3. Results

Spectra of light sources used

Figure 3.6: Solar simulator spectrum: xenon arc lamp filtered for IR radiation with a circulating $H_2SO_4 \cdot CuSO_4$ solution filter. Schott glass filters are used with this source. With filter WG305 is referred to as SS + UVB and with filter WG345 is referred to as SS – UVB.

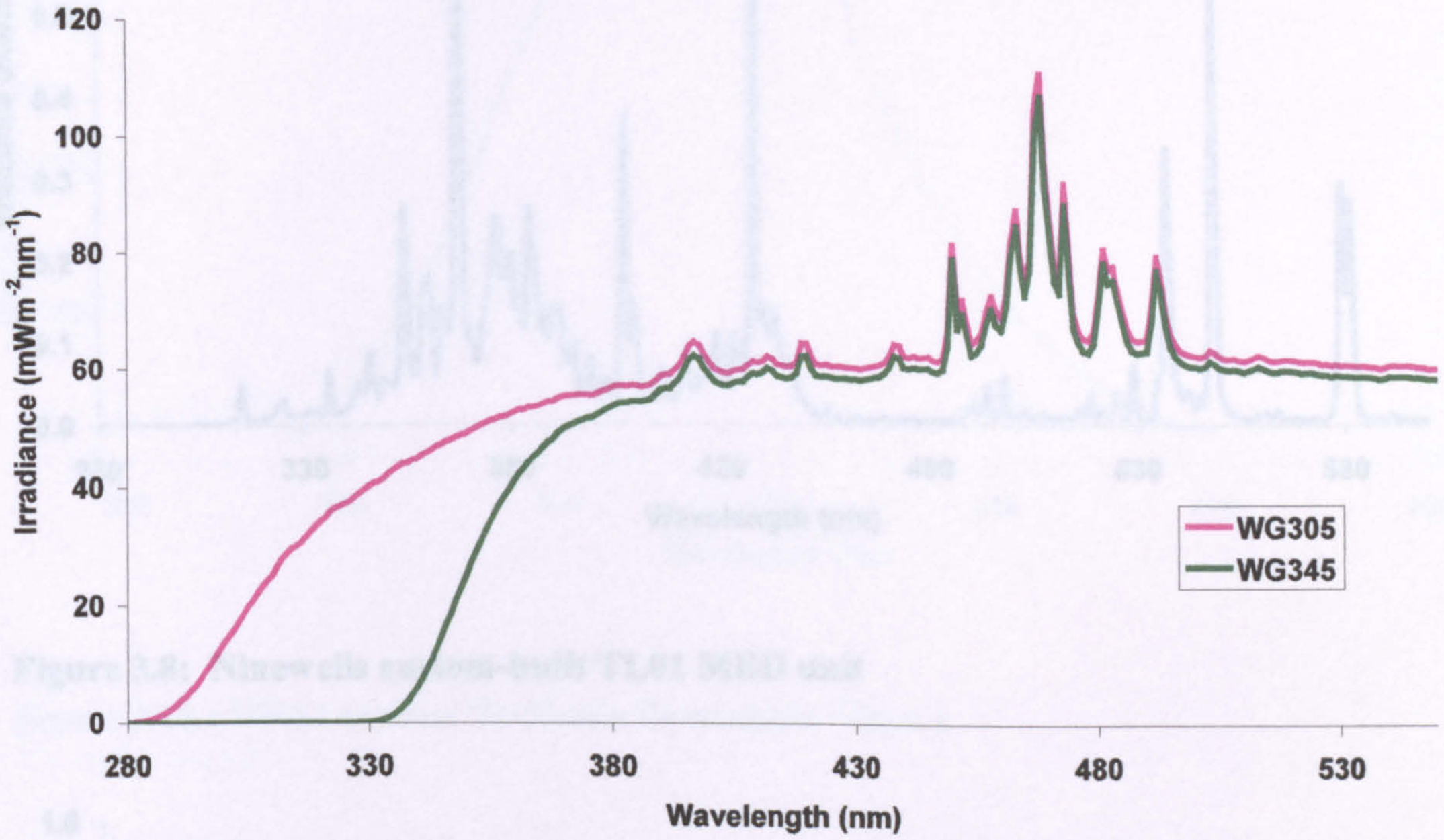


Figure 3.7: Provocation source: Dr Honle UVA blue light source (metal halide) with hl1 filter

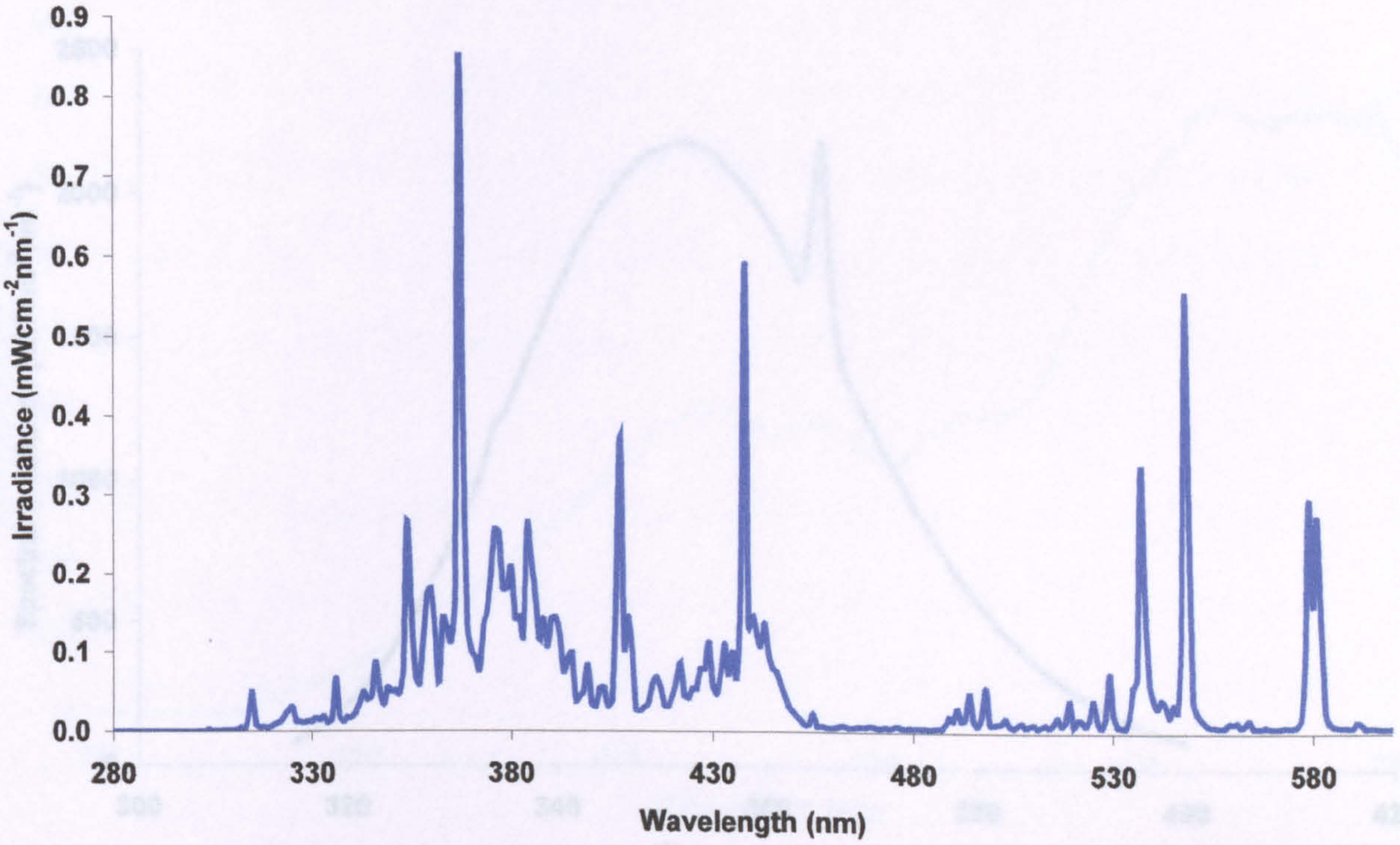


Figure 3.8: Ninewells custom-built TL01 MED unit

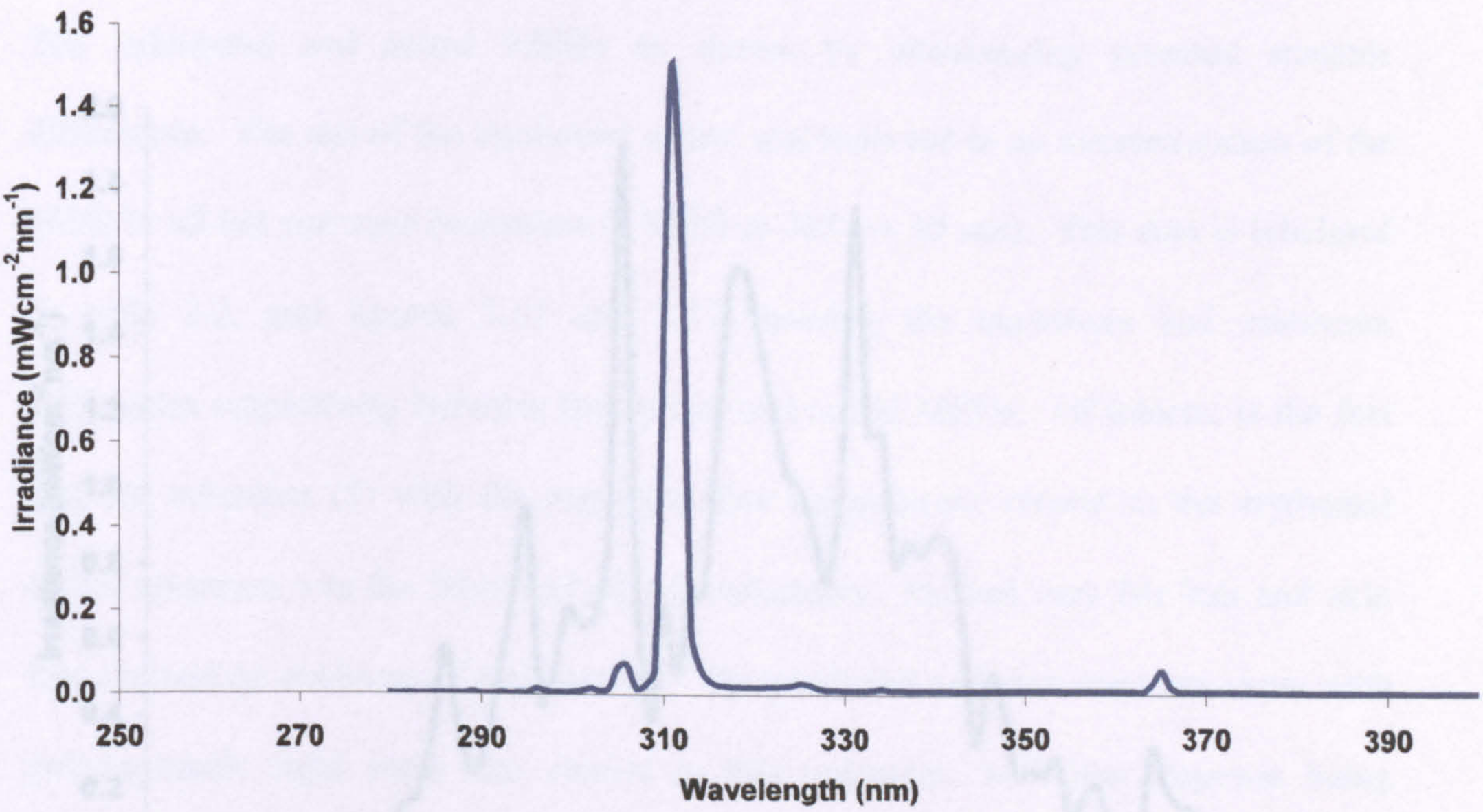


Figure 3.9: Ninewells custom-built UVA MED unit

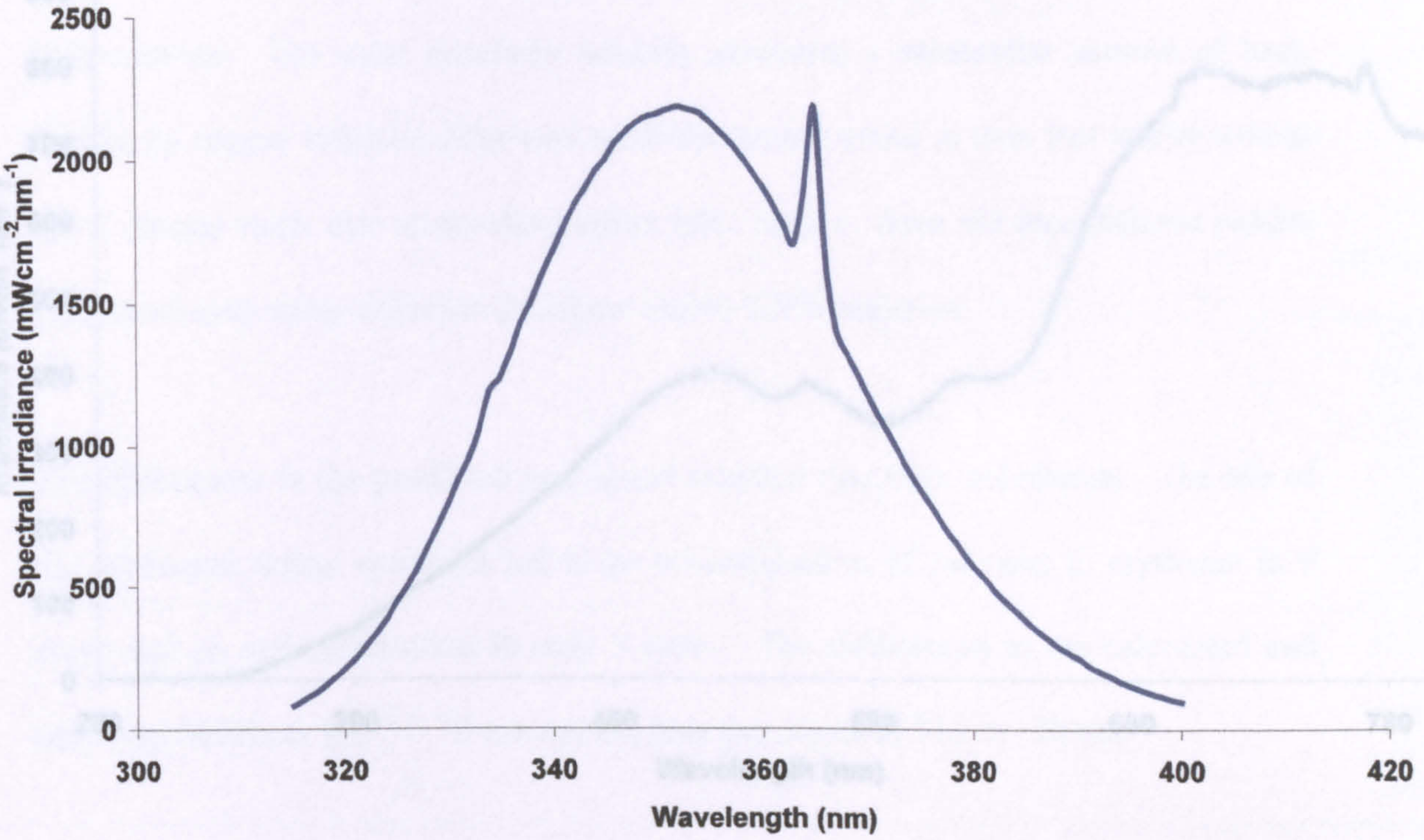


Figure 3.10 : UVA1 source: Dr Honle Dermalight Ultra 1

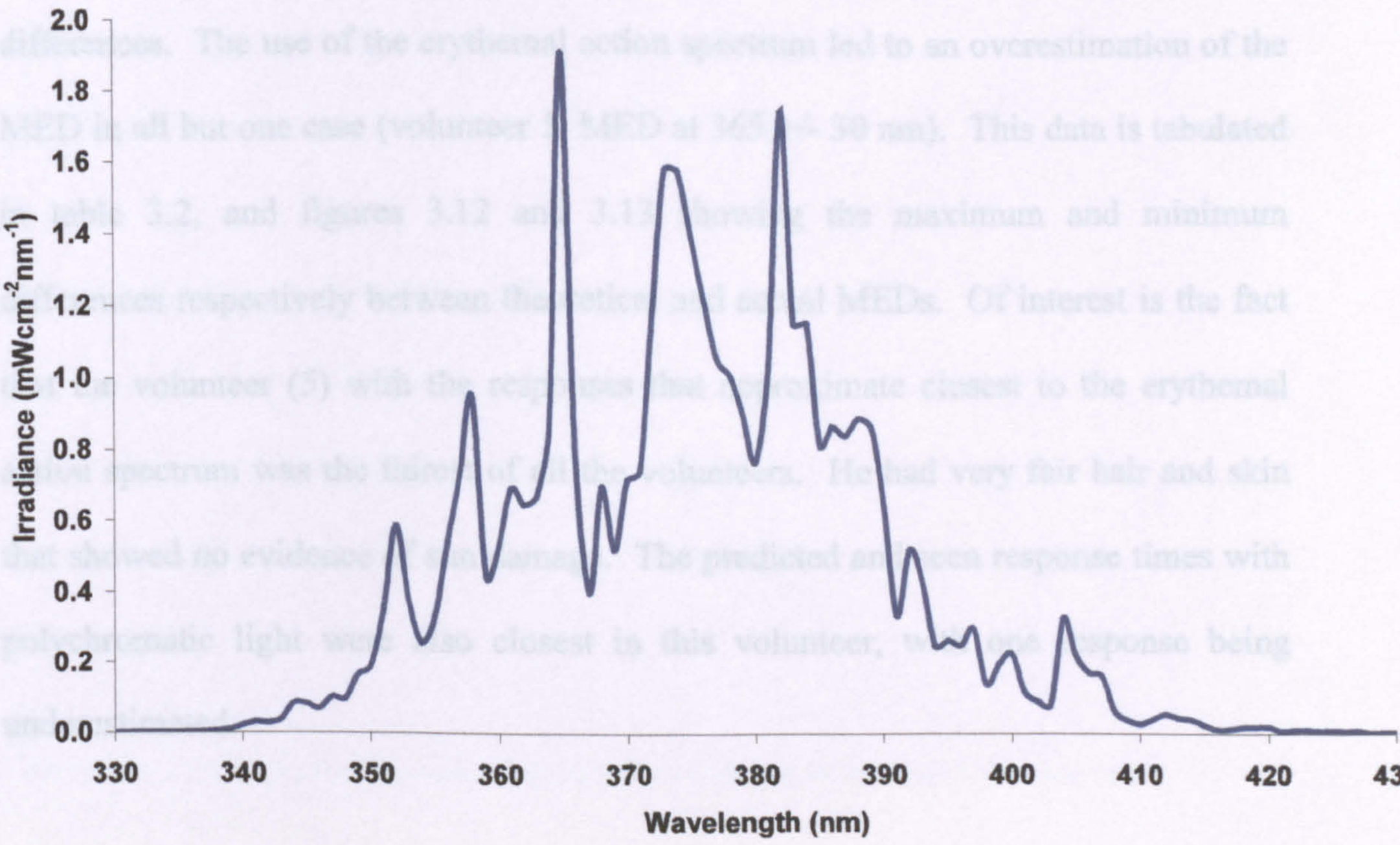
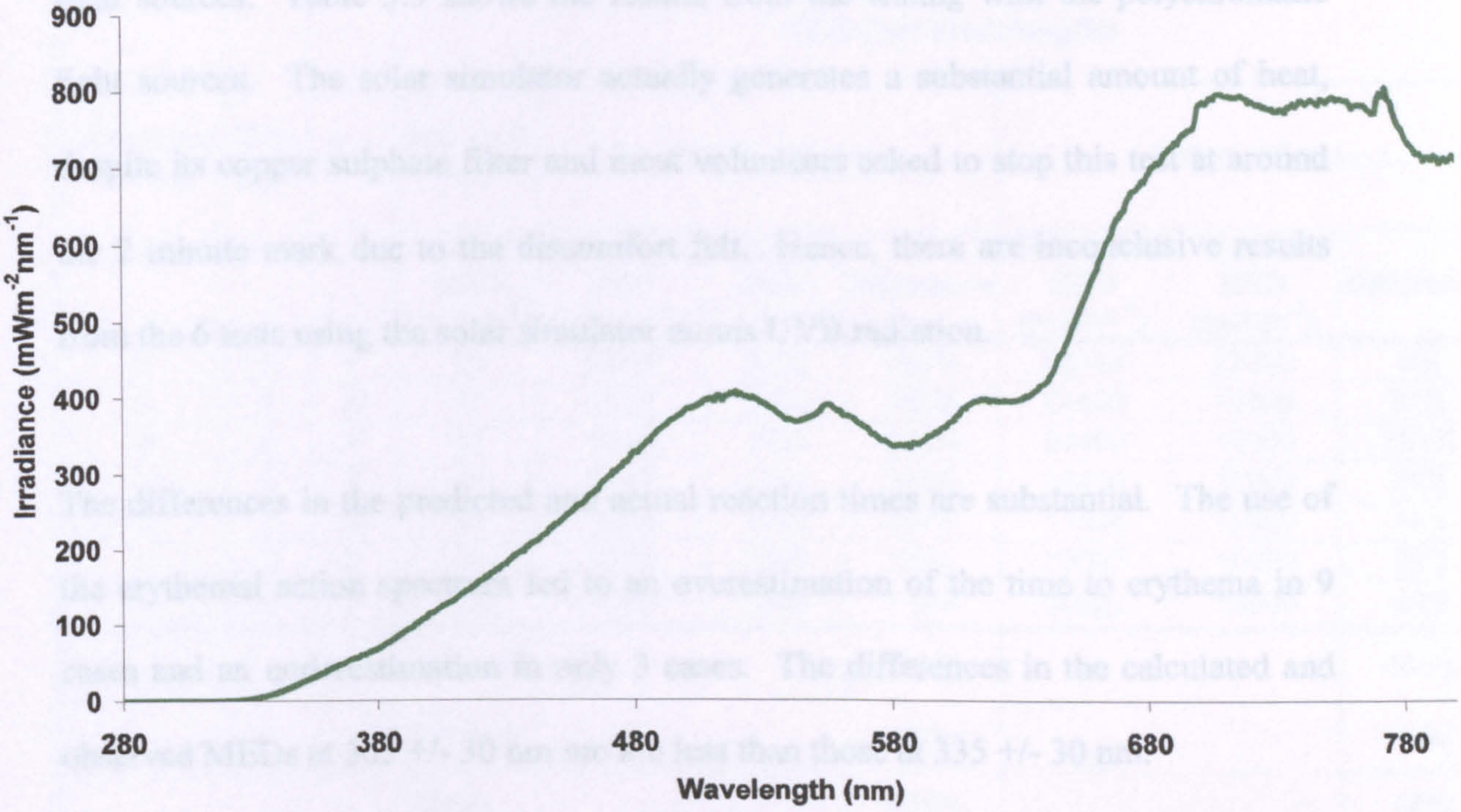


Figure 3.11: Theatre light: Daray portable theatre light



Normal subjects

The calculated and actual MEDs as shown by phototesting revealed sizeable differences. The use of the erythemal action spectrum led to an overestimation of the MED in all but one case (volunteer 5, MED at 365 +/- 30 nm). This data is tabulated in table 3.2, and figures 3.12 and 3.13 showing the maximum and minimum differences respectively between theoretical and actual MEDs. Of interest is the fact that the volunteer (5) with the responses that approximate closest to the erythemal action spectrum was the fairest of all the volunteers. He had very fair hair and skin that showed no evidence of sun damage. The predicted and seen response times with polychromatic light were also closest in this volunteer, with one response being underestimated.

A total of 20 tests were performed with polychromatic light, on 7 volunteers, using 4 light sources. Table 3.3 shows the results from the testing with the polychromatic light sources. The solar simulator actually generates a substantial amount of heat, despite its copper sulphate filter and most volunteers asked to stop this test at around the 2 minute mark due to the discomfort felt. Hence, there are inconclusive results from the 6 tests using the solar simulator minus UVB radiation.

The differences in the predicted and actual reaction times are substantial. The use of the erythemal action spectrum led to an overestimation of the time to erythema in 9 cases and an underestimation in only 3 cases. The differences in the calculated and observed MEDs at 365 +/- 30 nm nm are less than those at 335 +/- 30 nm.

Table 3.2: Calculated and observed MEDs for normal subjects from irradiation monochromator testing

Volunteer number	Skin type	Sex	Phototest Wavelengths						
			305 +/- 5 nm	335 +/- 30 nm			365 +/- 30 nm		
			Actual MED ($mJcm^{-2}$)	Calculated MED ($mJcm^{-2}$)	Actual MED ($mJcm^{-2}$)	Difference	Calculated MED ($mJcm^{-2}$)	Actual MED ($mJcm^{-2}$)	Difference
1	3	F	56	10356	3900	165%	29186	27000	8%
2	3	M	47	8692	2200	295%	24496	15000	63%
3	3	F	47	8692	1800	383%	24496	12000	104%
4	3	F	47	8692	2700	222%	24496	18000	36%
5	2	M	22	4068	1000	307%	11466	12000	-4%
6	3	F	39	7212	3900	85%	20327	15000	36%
7	2	F	39	7212	3300	119%	20327	18000	13%
Maximum*						383%			104%
Minimum						85%			4%
Mean						225%			38%

* Maximum, minimum and mean values calculated from root, mean squared percentage values.

Figure 3.12 : Maximum difference between theoretical and actual MED's, volunteer 3

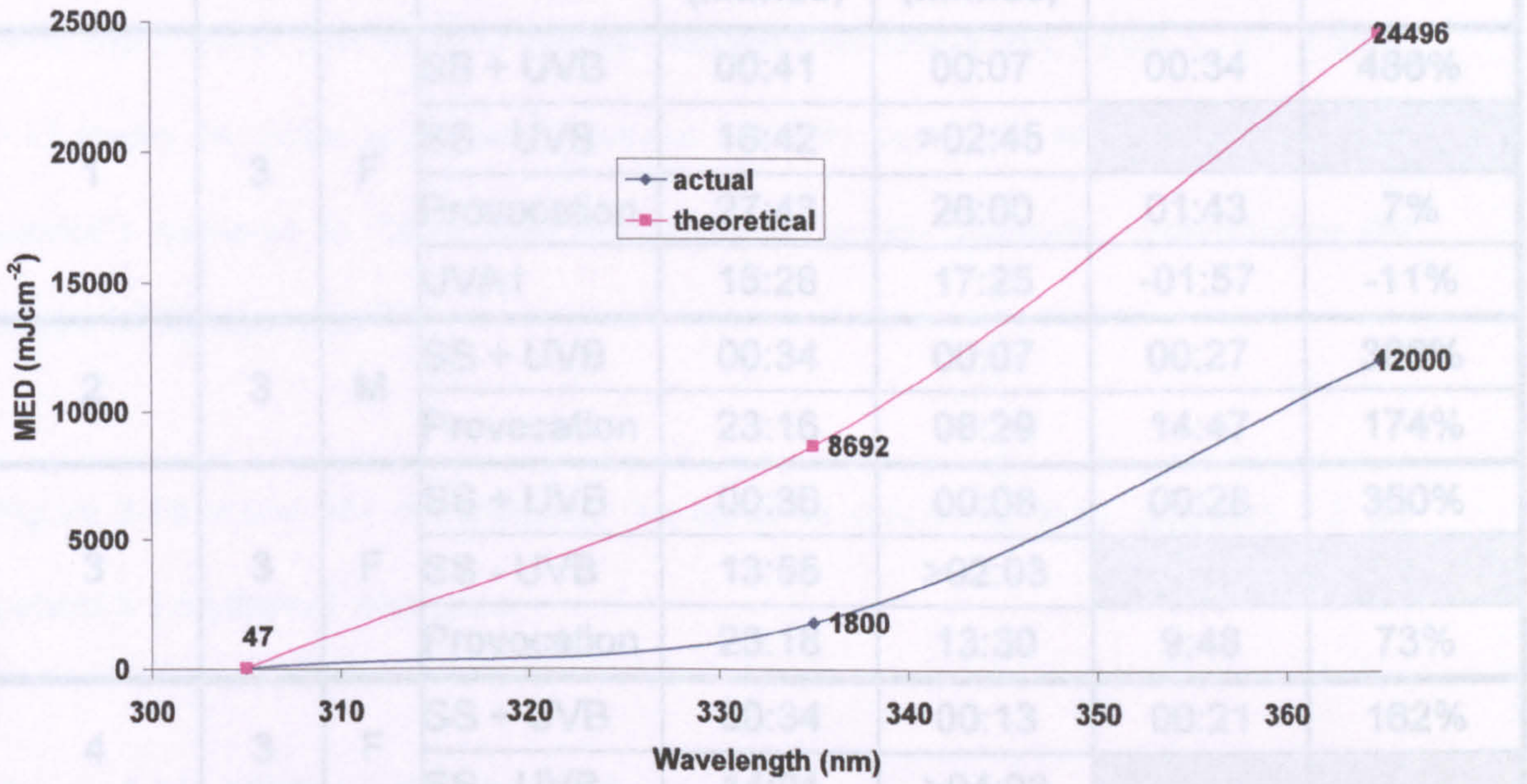


Figure 3.13 : Minimum difference between theoretical and actual MED's, volunteer 5

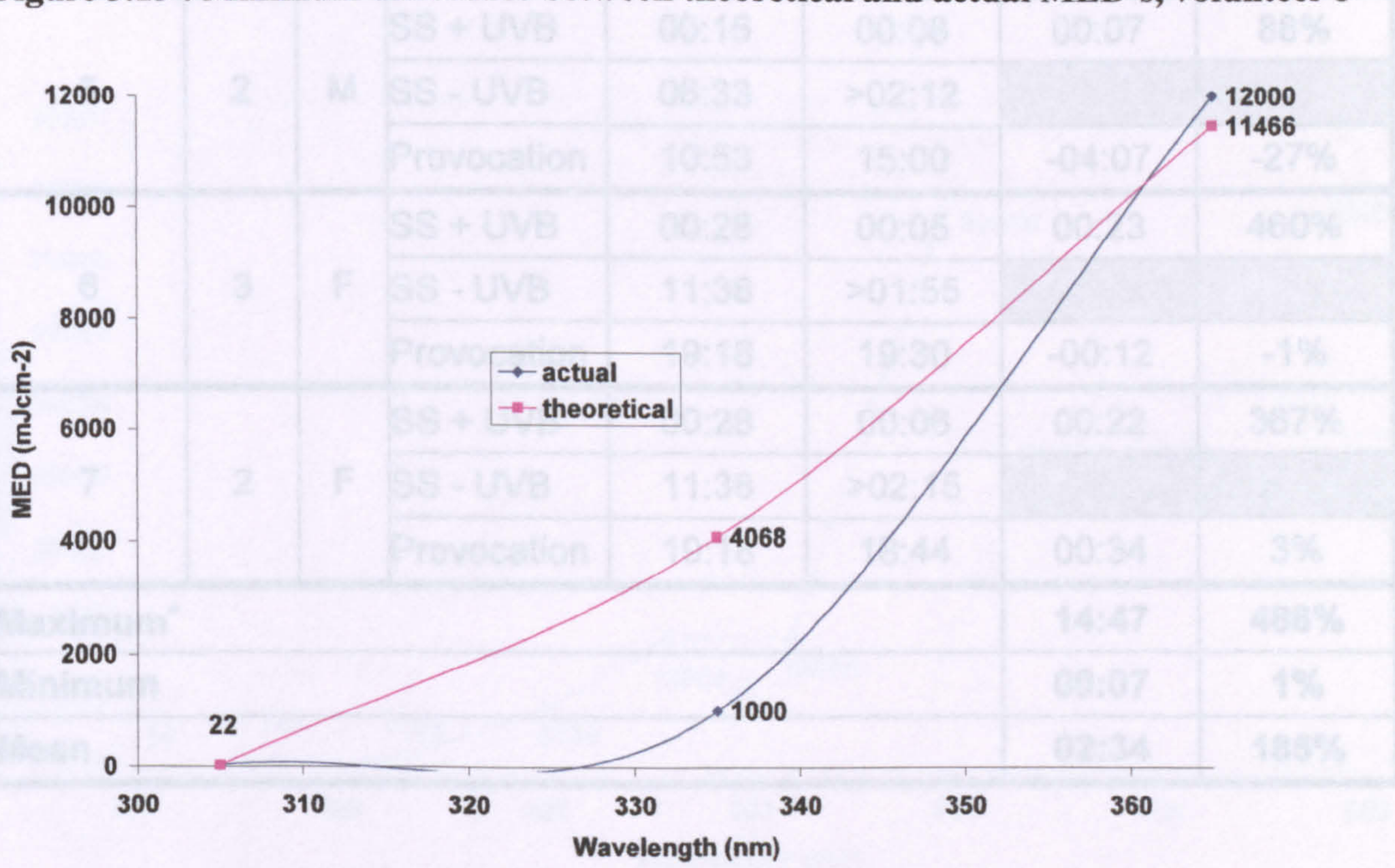


Table 3.3: Predicted and actual responses to polychromatic radiation for normal subjects

Volunteer number	Skin type	Sex	Source	Predicted time to erythema (mm:ss)	Actual time to erythema (mm:ss)	Difference (mm:ss)	Difference (%)
1	3	F	SS + UVB	00:41	00:07	00:34	486%
			SS - UVB	16:42	>02:45		
			Provocation	27:43	26:00	01:43	7%
			UVA1	15:28	17:25	-01:57	-11%
2	3	M	SS + UVB	00:34	00:07	00:27	386%
			Provocation	23:16	08:29	14:47	174%
3	3	F	SS + UVB	00:36	00:08	00:28	350%
			SS - UVB	13:55	>02:03		
			Provocation	23:18	13:30	9:48	73%
4	3	F	SS + UVB	00:34	00:13	00:21	162%
			SS - UVB	14:01	>04:03		
5	2	M	SS + UVB	00:15	00:08	00:07	88%
			SS - UVB	06:33	>02:12		
			Provocation	10:53	15:00	-04:07	-27%
6	3	F	SS + UVB	00:28	00:05	00:23	460%
			SS - UVB	11:38	>01:55		
			Provocation	19:18	19:30	-00:12	-1%
7	2	F	SS + UVB	00:28	00:06	00:22	367%
			SS - UVB	11:38	>02:15		
			Provocation	19:18	18:44	00:34	3%
Maximum*						**14:47**	**486%**
Minimum						**00:07**	**1%**
Mean						**02:34**	**185%**

* Maximum, minimum and mean values calculated from root, mean squared percentage values.

Abnormal patients

Action Spectra

The action spectra of those patients with CAD revealed that as expected the MEDs were much lower than those of normal skinned individuals (see figure 3.14). Figure 3.15 shows the action spectrum for patient 1 and the erythemal action spectrum. The patient's spectrum is flatter than the erythemal action spectrum, contradicting the results of Menage *et al* [35].

Figure 3.16 shows the interpolation equations as calculated from Equation 3.6 for patient 5's erythemal responses.

Figure 3.14: MED results of a CAD patient (1)

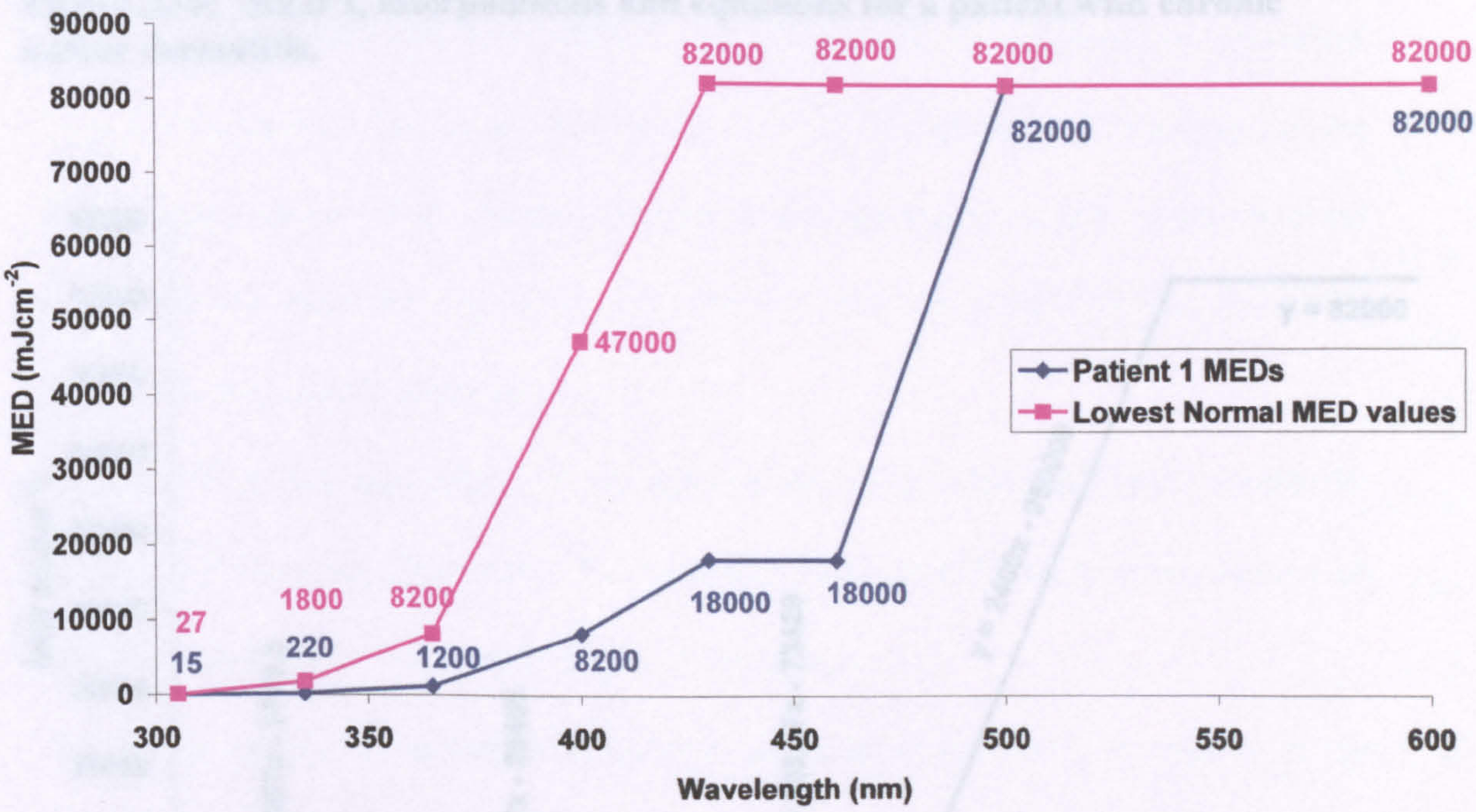


Figure 3.15: Log plot of the action spectrum of patient 1's sensitivity spectrum and the erythemal action spectrum (normalised to 305 nm)

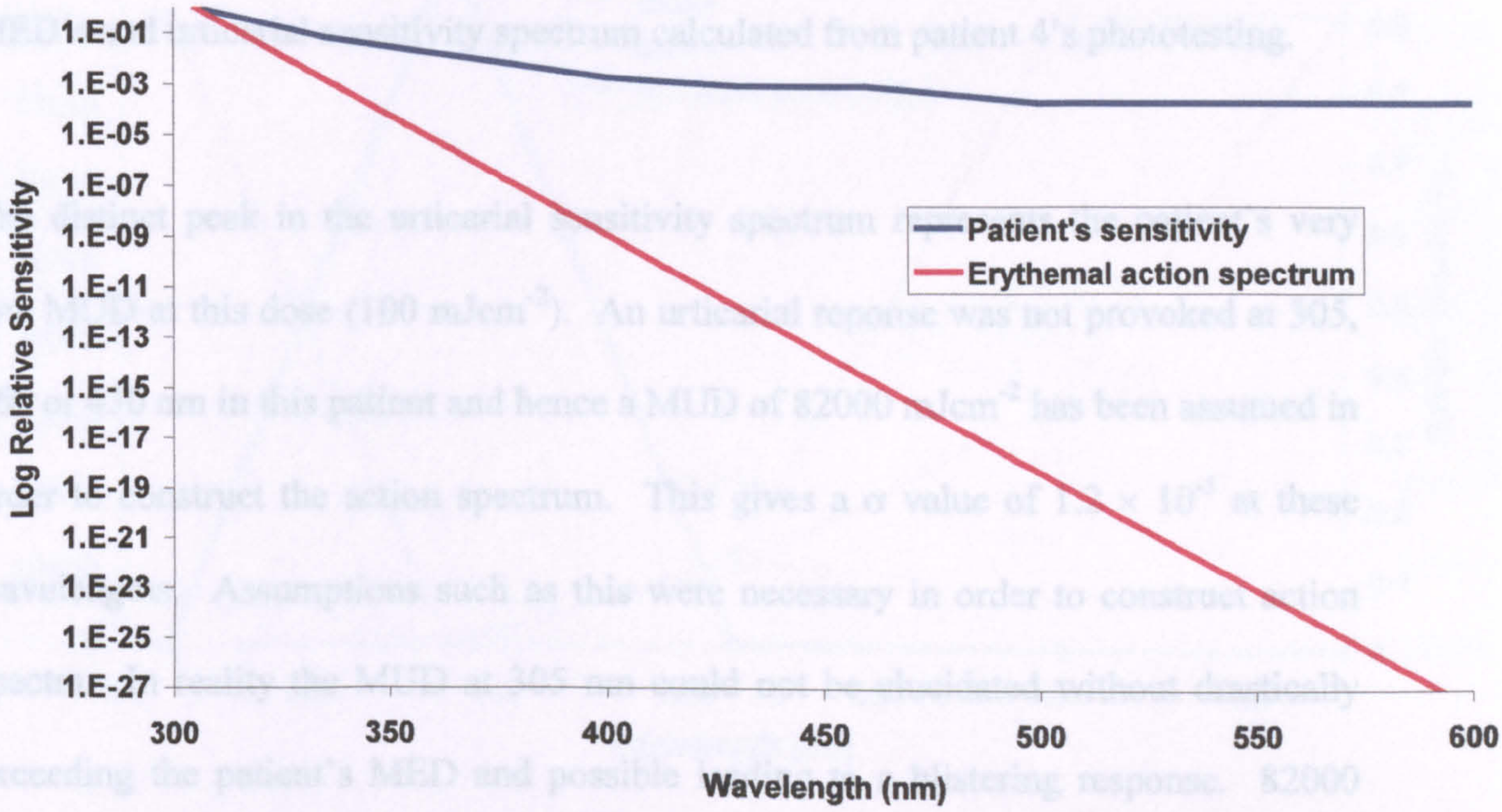
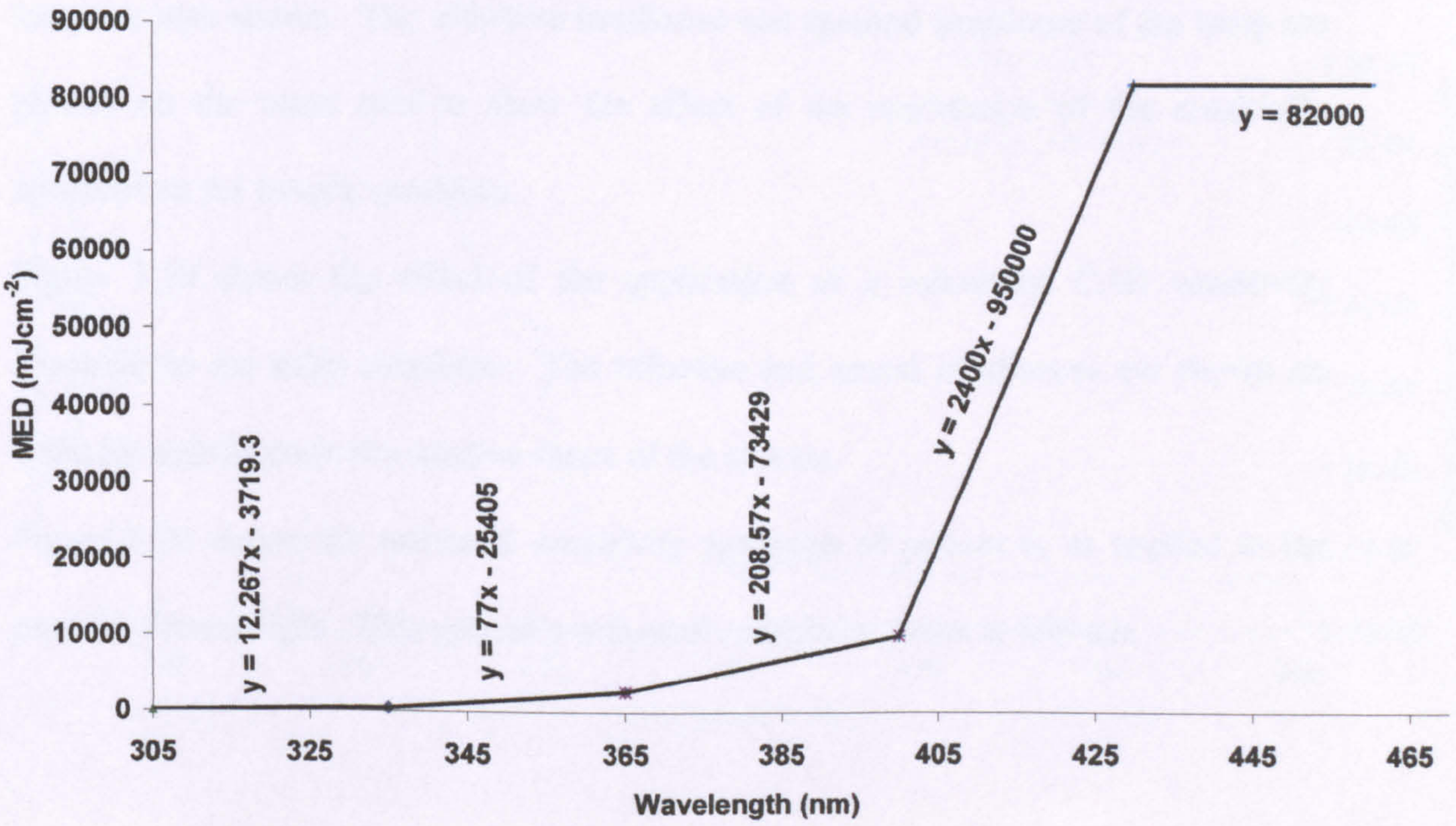


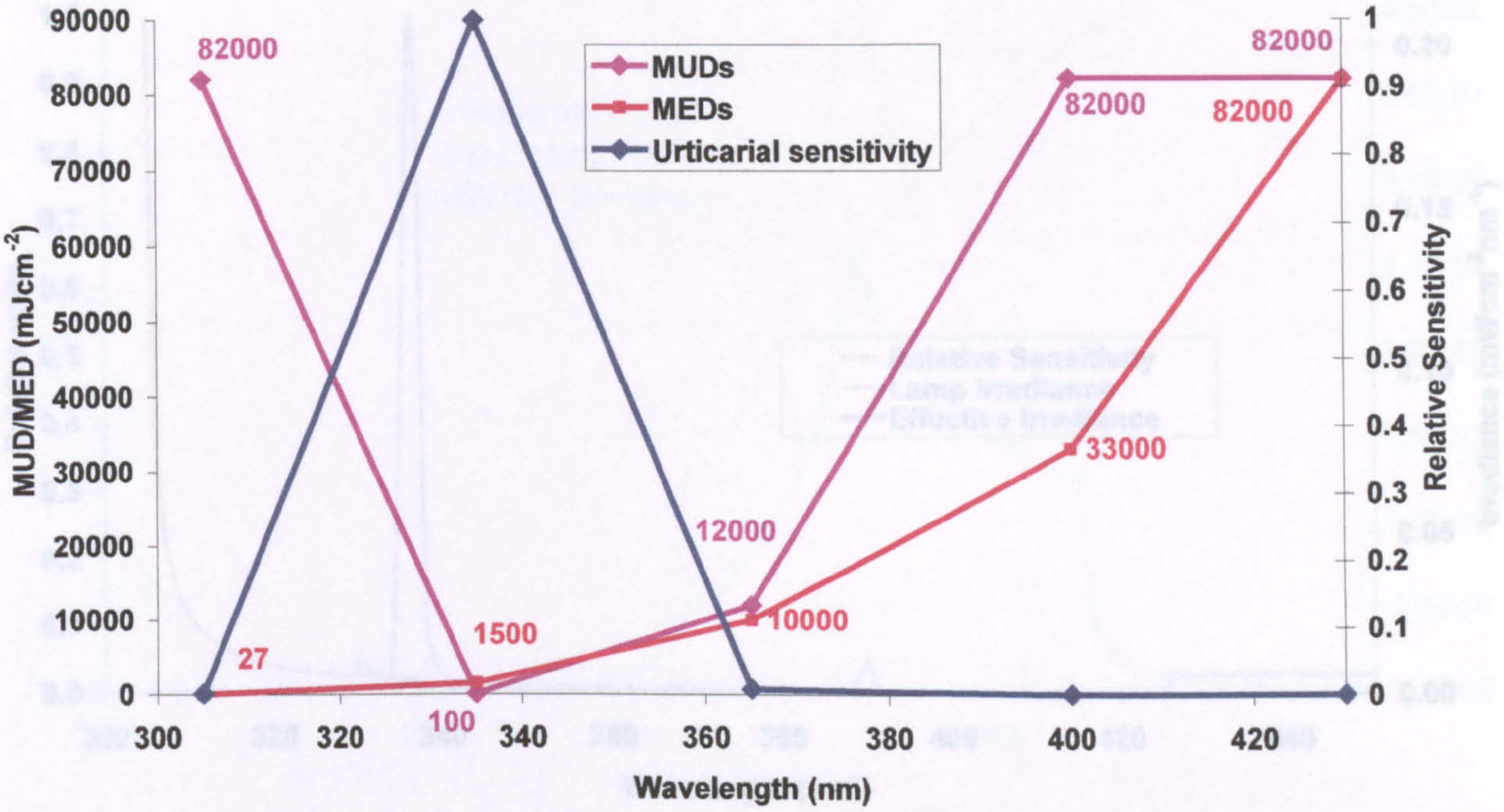
Figure 3.16: MED's, interpolations and equations for a patient with chronic actinic dermatitis.



As expected the urticarial action spectra for the SU patients was found to be very different from the erythema action spectrum. Urticaria was found to be caused by narrow wavebands in the monchromator testing. Figure 3.17 shows the MUD's, MED's and urticarial sensitivity spectrum calculated from patient 4's phototesting.

The distinct peak in the urticarial sensitivity spectrum represents the patient's very low MUD at this dose (100 $mJcm^{-2}$). An urticarial reponse was not provoked at 305, 360 or 430 nm in this patient and hence a MUD of 82000 $mJcm^{-2}$ has been assumed in order to construct the action spectrum. This gives a σ value of 1.2×10^{-5} at these wavelengths. Assumptions such as this were necessary in order to construct action spectra. In reality the MUD at 305 nm could not be elucidated without drastically exceeding the patient's MED and possible leading to a blistering response. 82000 $mJcm^{-2}$ was used consistently throughout this work to estimate a response that was unlikely as it represents the lowest normal MED at 430 nm upwards.

Figure 3.17: MUD's, MED's and urticarial sensitivity spectrum for patient 4



Polychromatic testing results

Figure 3.18 shows the effective irradiance for a TL01 source as calculated for patient 15, a CAD patient. The sensitivity spectrum and the unweighted irradiance of the lamp are also shown. The effective irradiance and spectral irradiance of the lamp are plotted on the same axis to show the effect of the application of the sensitivity spectrum to the lamp's spectrum.

Figure 3.19 shows the effect of the application of a calculated CAD sensitivity spectrum to the solar simulator. The effective and actual irradiances are shown on different axis to show the relative shape of the spectra.

Figure 3.20 shows the urticarial sensitivity spectrum of patient 6, as applied to the portable theatre light. This patient's urticarial sensitivity peaks at 460 nm.

Figure 3.18: Patient 15 relative sensitivity and the effective irradiance of a TL01 source.

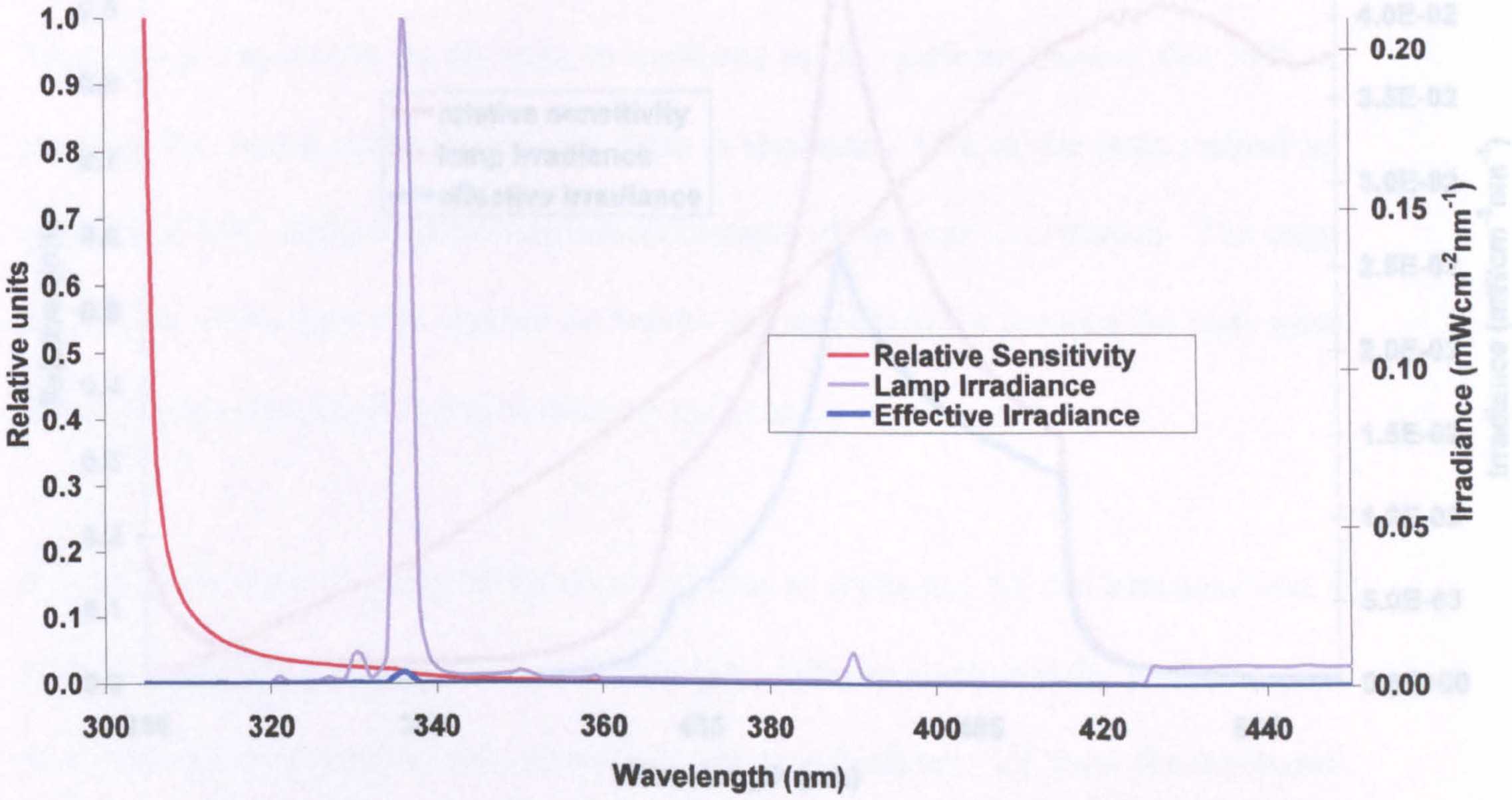


Figure 3.19: The relative sensitivity of patient 9, and as applied to the solar simulator – UVB radiation

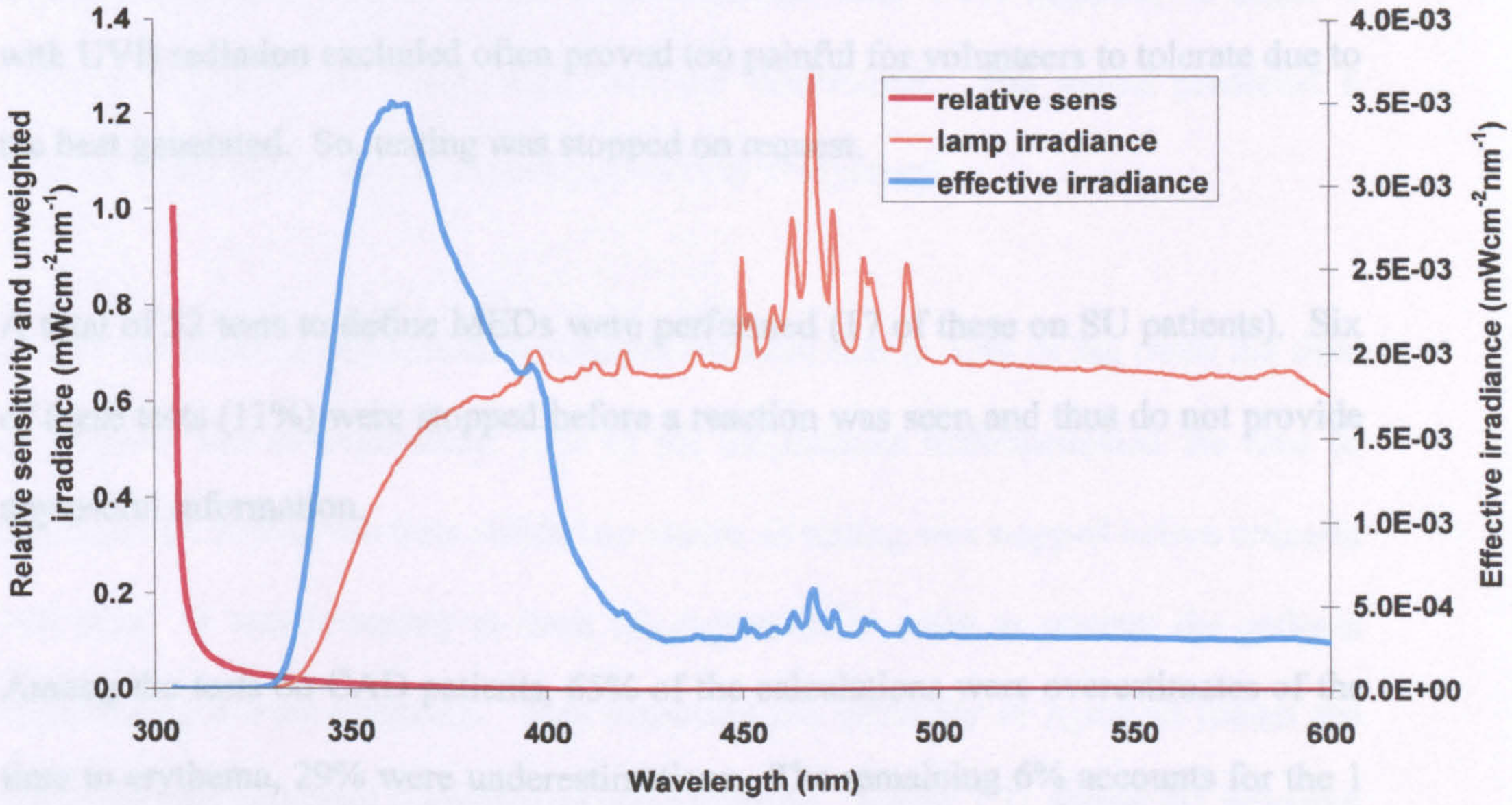
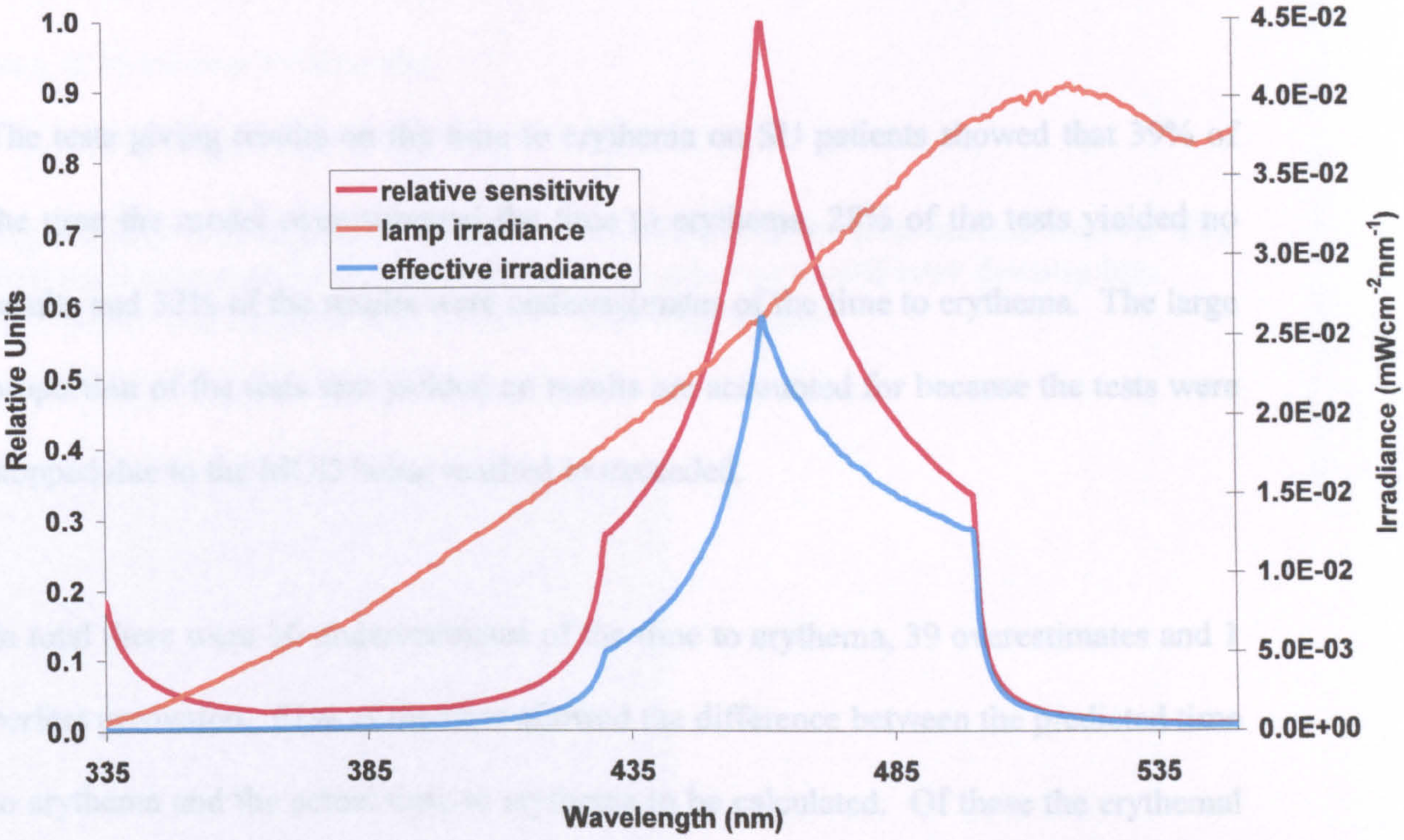


Figure 3.20: The relative sensitivity of patient 6, and as applied to the portable theatre light



The results from the testing of abnormal patients with polychromatic sources is shown in table 3.4. The sources chosen for testing were dependent on the amount of space available on the patient's back. As with the normal volunteers, the solar simulator with UVB radiation excluded often proved too painful for volunteers to tolerate due to the heat generated. So, testing was stopped on request.

A total of 52 tests to define MEDs were performed (17 of these on SU patients). Six of these tests (11%) were stopped before a reaction was seen and thus do not provide any useful information.

Among the tests on CAD patients, 65% of the calculations were overestimates of the time to erythema, 29% were underestimations. The remaining 6% accounts for the 1

test that gave no results (testing was stopped before a reaction was seen) and the 1 perfect test result.

The tests giving results on the time to erythema on SU patients showed that 39% of the time the model overestimated the time to erythema, 28% of the tests yielded no results and 33% of the results were underestimates of the time to erythema. The large proportion of the tests that yielded no results are accounted for because the tests were stopped due to the MUD being reached or exceeded.

In total there were 16 underestimates of the time to erythema, 39 overestimates and 1 perfect prediction. 61% of the tests allowed the difference between the predicted time to erythema and the actual time to erythema to be calculated. Of these the erythemal responses were predicted to within a mean time of 3 minutes and 52 seconds ($\geq$ 0 mins 0 secs, $\leq$ 51 minutes 54 seconds). The remaining 28% that did provide results only showed whether the reaction was an overestimate or an underestimate. For example, patient 1 reacted to the solar simulator with UVB radiation in under 4 seconds, although the actual MED was not determined. The model predicted 6 seconds so the result was an overestimated time to erythema.

The 17 urticarial response tests conducted revealed that in 53% of the cases the time to urticaria was overestimated, 12% of the calculations underestimated the time to urticaria and 35% of the tests yielded no results as testing was stopped before urticaria was seen. It was necessary to limit the exposures in order to prevent the patients experiencing severe erythema. This illustrates the difficulty in trying to model the erythemal and urticarial responses in solar urticaria. Figure 3.21 shows the urticarial

responses of patient 4 to the provocation source. Of the tests that did give results, it was possible to predict the time to urticaria in 2 minutes and 57 seconds ($\geq$ 0 mins 5 secs, $\leq$ 15 minutes 19 seconds).

Figure 3.21: The urticarial responses of patient 4 to the provocation source. The first exposure, seen in the top left square (1 minute) would later develop into erythema. The MUD is seen in the 2nd dose (top right).

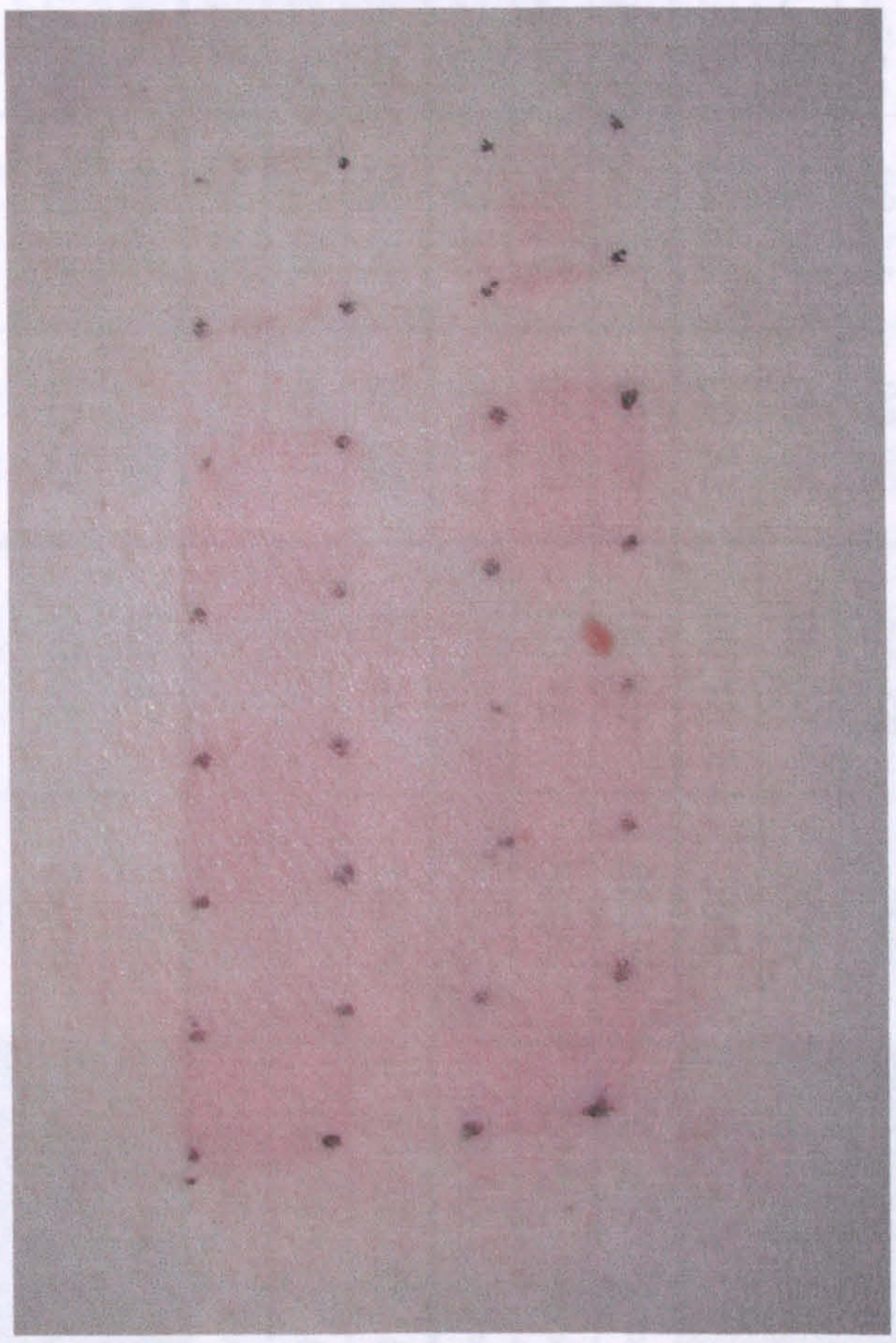


Table 3.4: Predicted and actual responses of abnormal skin to polychromatic radiation

Volunteer number	Skin type	Condition	Sex	Source	Predicted time to erythema (mm:ss)	Actual time to erythema (mm:ss)	Difference (mm:ss)	Difference (%)	Predicted time to urticaria (mm:ss)	Actual time to urticaria (mm:ss)	Difference (mm:ss)	Difference (%)
1	3	CAD	F	Provocation	04:50	00:30	04:20	867%				
				SS + UVB	00:06	<00:04						
				SS - UVB	02:37	02:30	00:07	5%				
2	2	CAD	F	Provocation	02:34	03:32	-00:58	-27%				
				SS + UVB	00:09	00:05	00:04	80%				
				SS - UVB	00:48	00:32	00:16	50%				
3	3	SU	F	Provocation	06:51	01:02	05:49	563%	12:59	>04:00		
				SS + UVB	00:18	00:03	00:15	500%	01:21	>00:10		
				SS - UVB	02:55	>02:23			03:10	>02:23		
4	3	SU	F	Provocation	02:48	01:00	01:48	180%	17:37	02:18	15:19	666%
				SS + UVB	00:05	>00:11			01:21	00:03	01:18	2600%
				SS - UVB	03:47	>02:36			04:38	>02:36		
5	2	CAD	F	Provocation	03:47	01:00	02:47	278%				
				SS + UVB	00:11	00:03	00:08	267%				
				SS - UVB	01:38	01:32	00:06	7%				

Volunteer number	Skin type	Condition	Sex	Source	Predicted time to erythema (mm:ss)	Actual time to erythema (mm:ss)	Difference (mm:ss)	Difference (%)	Predicted time to urticaria (mm:ss)	Actual time to urticaria (mm:ss)	Difference (mm:ss)	Difference (%)
6	2	SU	M	SS + UVB	00:36	00:03	00:33	1100%	00:01	00:07	-00:06	-86%
				SS - UVB	03:27	>00:05			00:10	00:05	00:05	100%
				Theatre	3:35:58	>40:00			04:49	04:30	00:19	7%
7	2	CAD	F	Provocation	7:17	<03:00						
				SS + UVB	0:11	<00:01						
				SS - UVB	3:43	02:49	00:54	32%				
8	2	SU	F	SS + UVB	00:22	00:18	00:04	22%	00:33	00:18	00:15	83%
				Provocation	06:38	10:00	-03:22	-34%	04:00	15:28	11:28	74%
9	3	CAD	F	SS + UVB	00:33	00:09	00:24	267%				
				SS - UVB	02:53	02:40	00:13	8%				
10	3	CAD	M	Provocation	19:57	28:00	-08:03	-29%				
				UVA	20:08	>13:00						
				TL01	16:59	02:44	14:15	521%				
11	2	CAD	F	SS + UVB	00:03	<00:01						
				SS - UVB	01:44	>02:34						

Volunteer number	Skin type	Condition	Sex	Source	Predicted time to erythema (mm:ss)	Actual time to erythema (mm:ss)	Difference (mm:ss)	Difference (%)	Predicted time to urticaria (mm:ss)	Actual time to urticaria (mm:ss)	Difference (mm:ss)	Difference (%)
12	2	CAD	F	Provocation	12:49	11:45	01:04	9%				
				SS + UVB	00:33	00:07	00:26	371%				
				SS - UVB	03:54	02:17	01:37	71%				
13	3	CAD	F	Provocation	00:45	01:45	-01:00	-57%				
				SS + UVB	00:02	00:04	-00:02	-50%				
				SS - UVB	00:56	>01:30						
14	3	SU	M	SS + UVB	00:04	<00:03			05:51	>00:10		
				SS - UVB	00:51	>01:36			07:11	>01.57		
15	5	CAD	F	SS + UVB	15:36	06:00	09:36	160%				
				TL01	12:49	00:35	12:14	2097%				
16	2	SU	M	SS + UVB	00:06	>00:12			01:20	00:23	00:57	248%
				SS - UVB	00:56	>01:09			01:26	00:49	00:37	76%
17	5	CAD	M	Provocation	02:55	<02:00						
				SS + UVB	00:08	00:04	00:04	100%				
				SS - UVB	00:47	>01:16						

Volunteer number	Skin type	Condition	Sex	Source	Predicted time to erythema (mm:ss)	Actual time to erythema (mm:ss)	Difference (mm:ss)	Difference (%)	Predicted time to urticaria (mm:ss)	Actual time to urticaria (mm:ss)	Difference (mm:ss)	Difference (%)
18	2	CAD	F	Provocation	02:09	03:32	-01:23	-39%				
				SS + UVB	00:06	00:06	00:00	0%				
				SS - UVB	00:51	00:53	-00:02	-4%				
				TL01	01:31	00:23	01:08	296%				
				MPD	01:32	04:14	-02:42	-64%				
19	2	SU	M	Provocation	11:11	>10:00			03:22	01:30	01:52	124%
				TL01	52:39	00:45	51:54	6920%	01:18	01:04	00:14	22%
Maximum							51:54	6920%			15:19	2600%
Minimum							00:00	0%			00:05	7%
Mean							03:52	457%			02:57	371%

4. Discussion

Normal Subjects

The results from this study were surprising. The fact that the erythemal action spectrum led to an overestimation of the MEDs in all cases points to the conclusion that the erythemal action spectrum should not be used to estimate the time to erythema for polychromatic sources. Of note is the fact that the calculations and actual MEDs at 365 +/- 30 nm were closer than those at 335 +/- 30 nm. This may indicate the involvement of more than one chromophore at ~ 335 nm. The disagreement in observed and predicted results is possibly due to the erythemal response being non linear, as suggested by Sutherland [46] but the fact that other investigators have shown the erythemal action spectrum to be plausible [30,31] indicates that the reasons for this finding may be due to errors inherent in the phototesting method.

The determination of the MED is never exact, as the actual MED may lie anywhere between just above the dose where a response is not seen and the dose where it is visible. This constitutes a systematic uncertainty in the phototest system [32]. Using finer dose increments could reduce these uncertainties but this would increase the time necessary for testing and was not practical while using unpaid volunteers.

Furthermore, there are errors inherent in the determination of the MEDs. Visual detection of erythema is subjective and dependent on the illumination [52]. These errors were minimised as far as practical by using experienced staff and a tungsten halogen source to illuminate the subjects' backs. It was disappointing that the use of an erythema meter could not help to provide an objective measure of the erythema, but

the results were so variable that the decision to abandon these measurements and rely on the human eye led to consistent results.

The bandwidth of the radiation is also important. Young & Diffey [32] showed that providing the monochromator bandwidth is kept constant in phototesting, the theoretical effectiveness of radiation at UVB wavelengths can be related to that at 300 nm. They assessed this by testing the MED at 300 nm and then predicting the MED at another wavelength using the erythemal action spectrum and testing to check their assumptions. Thus they did not use broad-spectrum polychromatic radiation.

In this study the MEDs at wavelengths across the UVB and UVA spectrum were related to that at 305 +/- 5 nm. The bandwidths used vary due to the output of the monochromators. Narrower bands could be used at 335 nm upwards but this would increase the dosage times considerably and is therefore not practical. It is recognised, therefore, that the MED measured at 365 nm in this study is due to radiation with a full width at half maximum of 30 nm. With constant bandwidths these errors cancel out (for UVB wavelengths) [32] but the difference in observed and expected MEDs found in this study may be due to these differences in bandwidths.

The fact that the erythemal action spectrum model did not transfer to polychromatic radiation is surprising. The erythemal effectiveness of the sources was calculated using the erythemal action spectrum and related to the MED at 305 +/- 5 nm. It is possible that the erythemal response to polychromatic radiation is not additive across the UVB and UVA wavebands due to the optical properties of the skin and chromophores therein, hence rendering the erythemal action spectrum redundant for

the assessment of the erythemal potential of broadband sources. However, the differences in observed and expected reactions may also be due to experimental error.

As well as the errors inherent in the phototesting method (as already discussed), the differences in observed and expected reaction times may be accounted for by the dosimetry methods used. The doses of the radiation used in phototesting are achieved using thermopiles and the dosimetry of the polychromatic sources is accomplished with a spectroradiometer. These two methods of dosimetry are related to different calibration chains at NPL and thus there may be differences in doses accounted for by uncertainties in the standards as well as by uncertainties inherent in the dosimetry methods. Consideration of the uncertainties in the spectroradiometer measurements is given in chapter 1. There is no uncertainty budget available for the thermopile measurements. This gap in knowledge should be addressed in order to provide proper quality assurance for these measurements.

During the course of this research, United Kingdom Accreditation Society (UKAS) accreditation was given to the unit's UV meter calibration procedures, and thus an uncertainty budget for spectral measurements was constructed. A similar assessment for thermopile measurements is indicated. Appendix 3.2 contains results of measurements made of the spectral distribution and beam uniformity of the monochromators used in phototesting. There is considerable non-uniformity of the beams, particularly at 305 +/- 5 nm. As can be seen from these results, a complex uncertainty budget for dosimetry of these instruments would be somewhat futile given the problems inherent in instruments. Attempts have been made to find more reliable

and uniform equipment for phototesting, but to date no instrument is available with suitably high output of visible light as well as UV radiation.

No concrete conclusions can be drawn from this study due to the small sample number. There are many pointers to a better experimental design, including phototesting at more wavelengths and an assurance of the dosimetry based on thermopiles. A study recruiting a large number of paid volunteers is suggested seeing as this action spectrum is so widely used and relied upon in photobiology.

Abnormal subjects

The testing of abnormal subjects also showed that the responses to polychromatic radiation could not be predicted based on results from monchromator phototesting. The spacing of the phototest points prevented more complex modelling of the action spectrum, such as curve fitting. The action spectra are certainly not comprised of straight lines but in the absence of more data points this is the only model that is mathematically robust.

With CAD patients the results are surprising, as the action spectrum for CAD has been said to be similar to that for erythema [35]. The identification of the chromophore involved in CAD would assist in modelling the action spectrum. Within the limits of this study, the response of patients with CAD to polychromatic light can be said to be non-linear but the inconclusive nature of the findings in erythema prevent more inferences being drawn regarding the nature of the chromophore involved in CAD. If phototesting of all patients was to be conducted at more wavelengths then a large amount of data could be collected and a more feasible model of the action spectrum

could be developed. The response to polychromatic light could then be matched to one of the integral equations suggested by Sutherland [46].

With urticaria patients the differences in predicted and observed responses an interrelation of the erythemal and urticarial responses is indicated and the simple model used in this study is not applicable to this condition. However, the errors in the MED/MUD determination and phototesting also apply as discussed above. The determination of a MUD is perhaps easier than an MED as urticaria can be felt. There is a characteristic raising of the skin that happens and perhaps leads to a more reliable determination of a MUD.

The overlap of the erythema and urticaria sensitivity in SU patients presents difficulties in the measurement of an action spectrum in these patients. SU and CAD have been found to co-exist in some patients [56] and it is possible that the same unidentified antigen is responsible for mediating both these conditions. The fact that CAD represents a spectrum of disorders [38] could mean that the primary stages of CAD are present in some (or all) SU sufferers although clinical manifestations of CAD are not seen due to the stage of the progression of the disease. An animal model for solar urticaria would allow for the construction of a complete action spectrum. The urticarial responses to polychromatic sources would then be easier to rationalise.

These results challenge the assumption that the potential hazards of sources can be predicted using a linear model of response and suggest that more work is needed to find the chromophores involved in disease processes and photosensitive skin. Even if this was achieved the feasible models for response to polychromatic light suggested

by Sutherland [46] may not be found to hold true for human skin. It must be remembered that the skin is a complex and multifaceted organ with many endogenous chromophores even in normal skin.

We may never be able to construct a mathematical equation to predict reactions to polychromatic light. Irradiation monochromator phototesting has been called 'pseudoscience' and criticised as a reductionist approach to clinical medicine [57]. This testing clearly has its place in the diagnosis of photosensitive skin conditions but it may be that it has been relied upon too much in helping patients manage their conditions by avoiding certain wavelengths. The extrapolation of these results to estimating the hazards of sources encountered in everyday life should be halted until more research is carried out and the interactions of wavelengths are better understood.

5. Conclusions

- The results are inconclusive due to uncertainties in the measurements. However, they point to the responses of normal, CAD and SU skin being non-linear.

- For erythema this challenges a central paradigm in photobiology.

Appendix 3.1

In order to gauge the magnitude of the risks of an operating theatre to photosensitive or photosensitised individuals, an operation to give PDT to a brain tumour was observed. The surgical team used all possible precautions to minimise the patient's exposure to light, which meant that the anaesthetist was working in sub optimal conditions in the anaesthetic room. The theatre was then visited when it was not in use and measurements were made of all the light sources that the patient had been exposed to. The department's bench based spectroradiometer was used for these measurements. The distances used were those that the patient would experience e.g. for the main theatre lights the input optics was placed level with the operating table.

Figure 3A1.1: Patient with a brain tumour receiving PDT. The laser fibre can be seen (red) and the light source illuminating the patients head is the microscope used by the surgeon to identify the demarcations of the tumour.

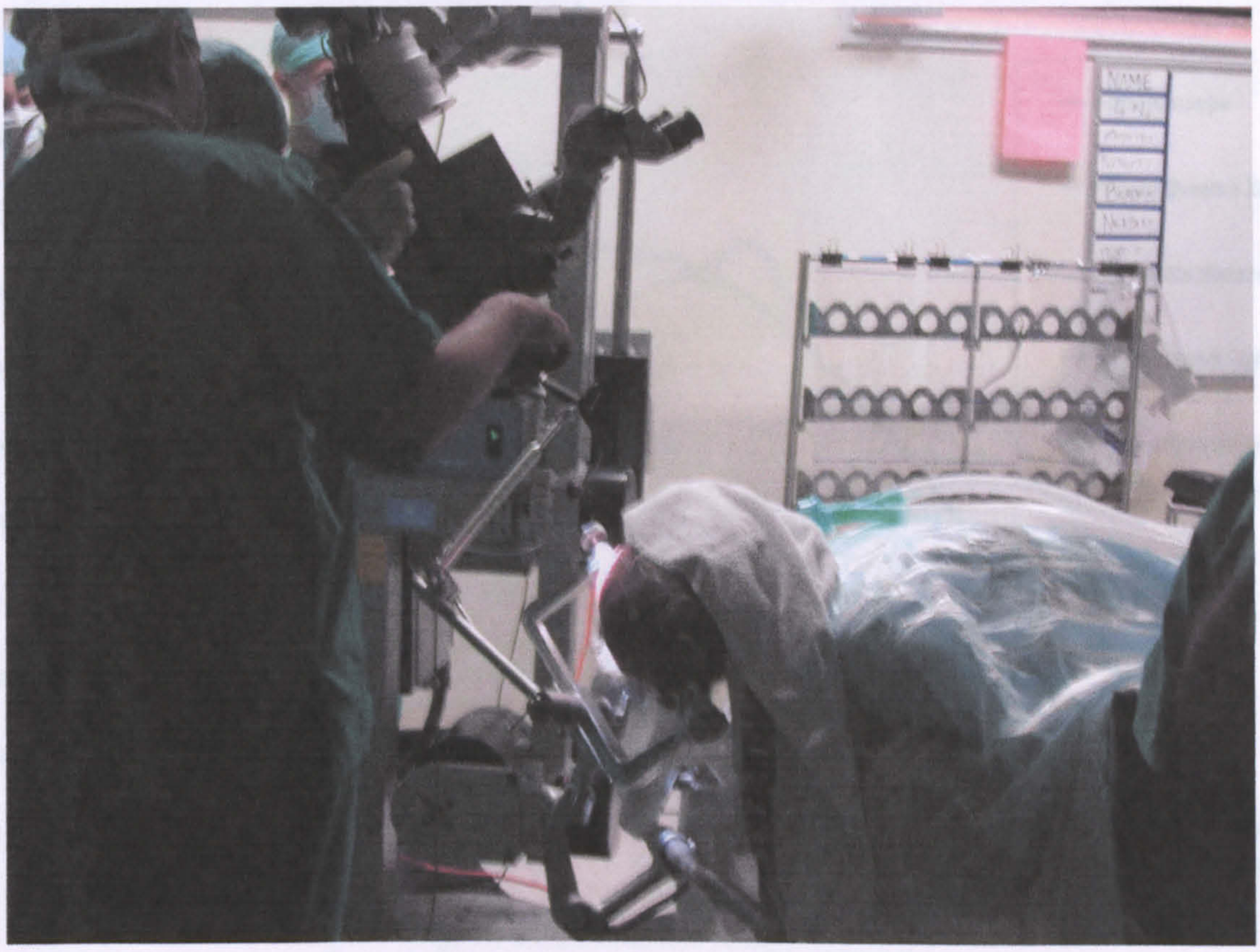
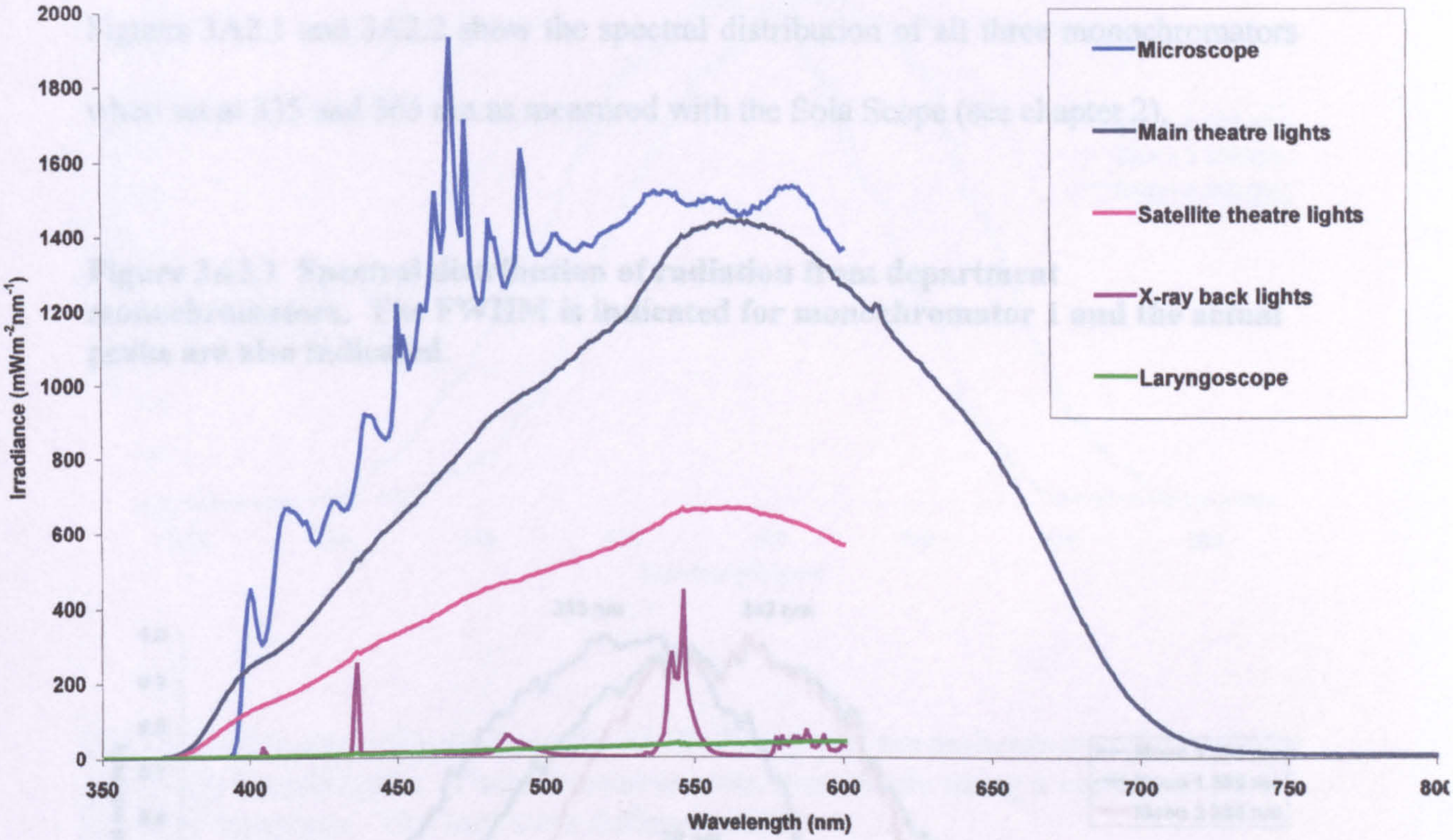


Figure 3A1.2: Irradiance from lights used in the neurology theatre at Ninewells Hopsital



Appendix 3.2

There are 3 monochromators in the photobiology unit. Monos 2 and 3 are routinely used for phototesting and mono 1 is used if necessary due to its output being lower. Figures 3A2.1 and 3A2.2 show the spectral distribution of all three monochromators when set at 335 and 365 nm as measured with the Sola Scope (see chapter 2).

Figure 3A2.1 Spectral distribution of radiation from department monochromators. The FWHM is indicated for monochromator 1 and the actual peaks are also indicated.

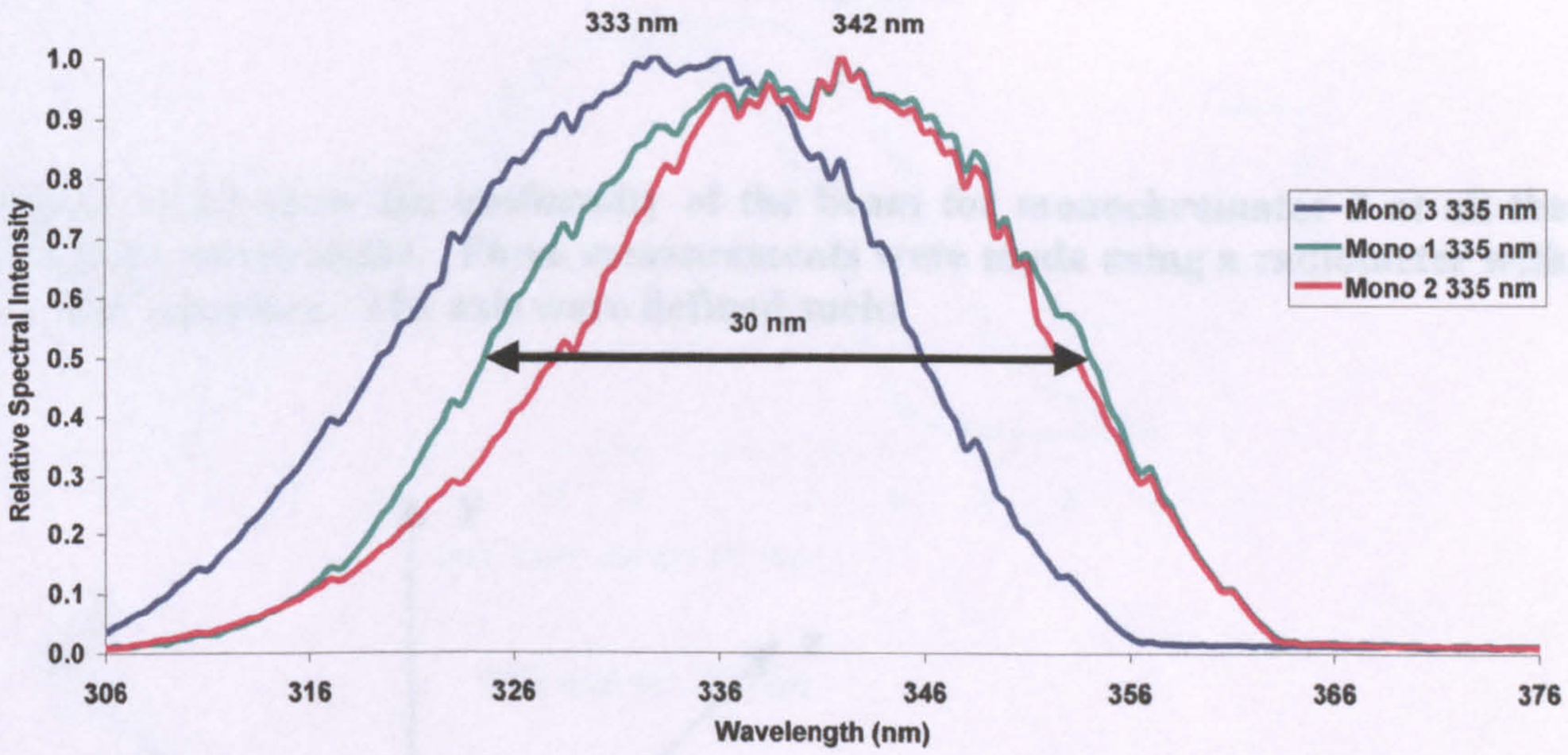


Figure 3A2.2 Spectral distribution of radiation from department monochromators. The FWHM is indicated for monochromator 1 and the actual peaks are also indicated

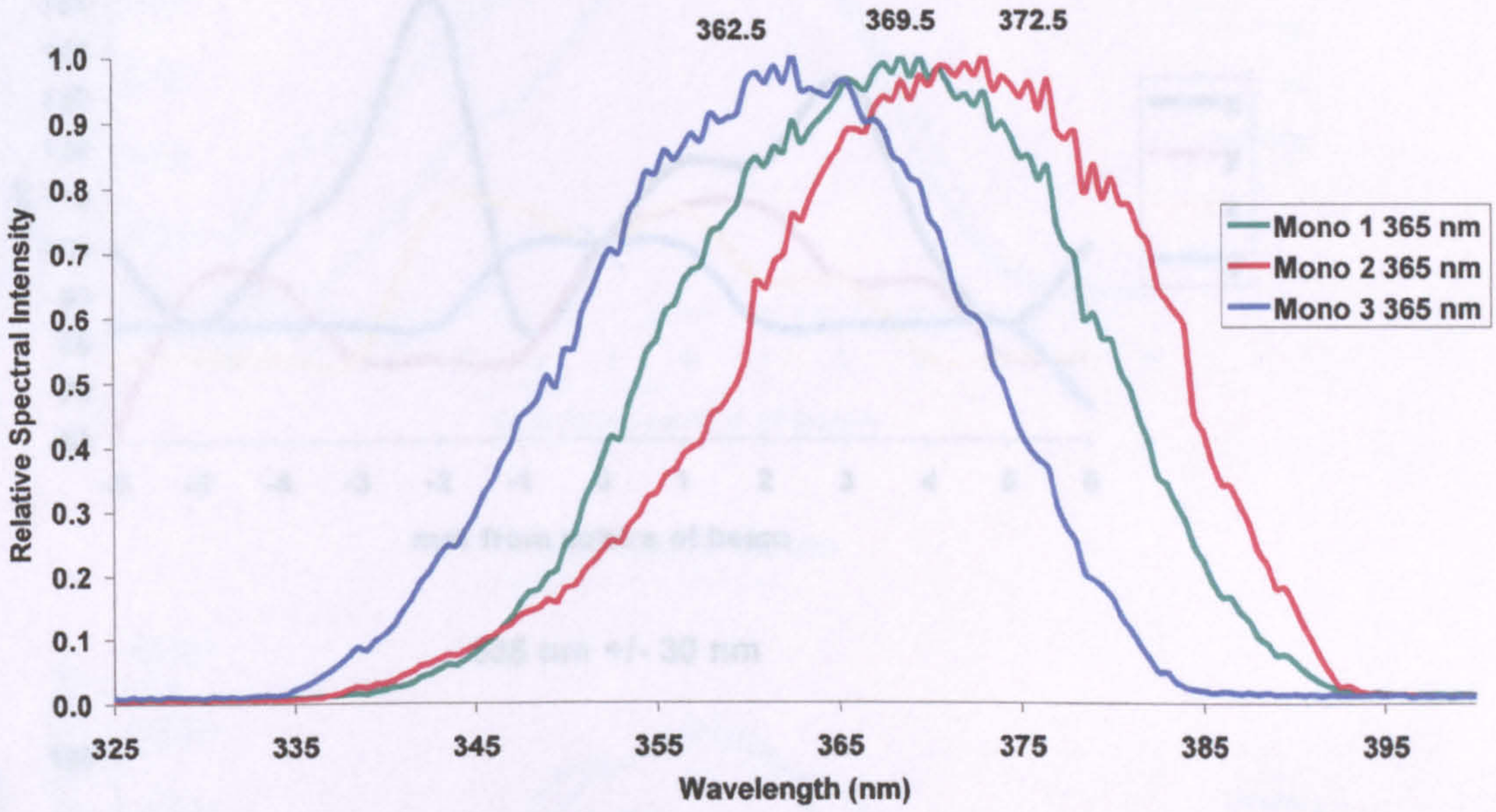


Figure 3A2.3 show the uniformity of the beam for monochromator 3 at all the phototest wavelengths. These measurements were made using a radiometer with a 1 mm^2 aperture. The axis were defined such:

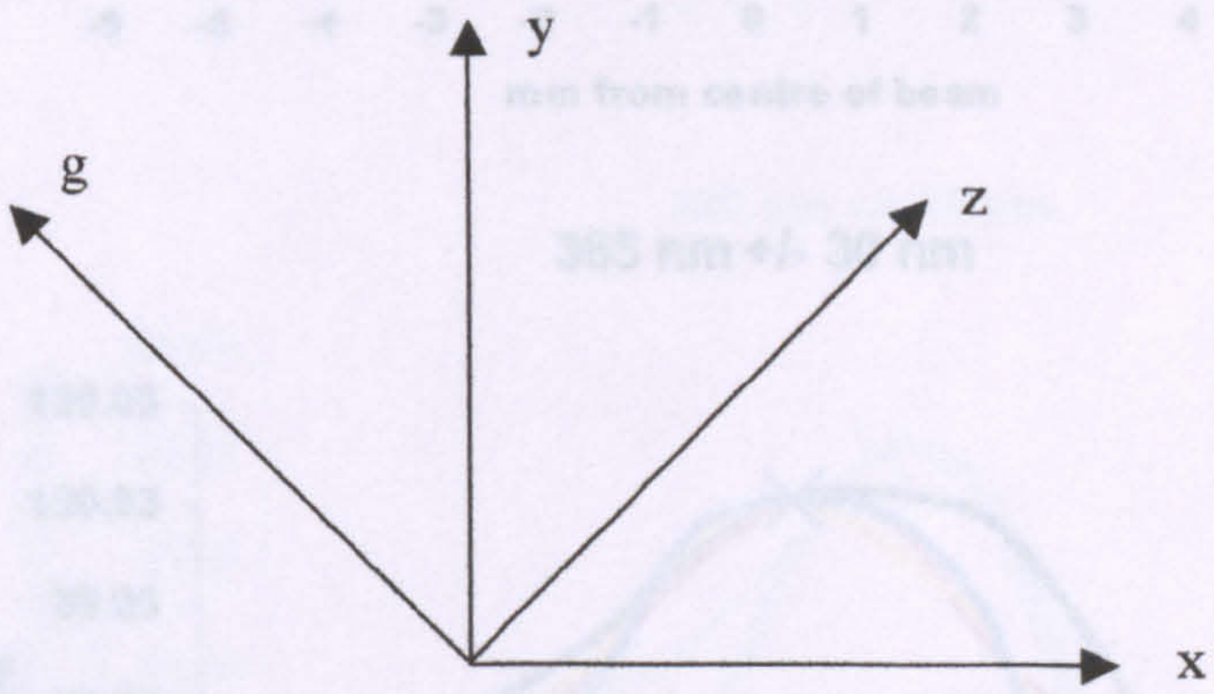
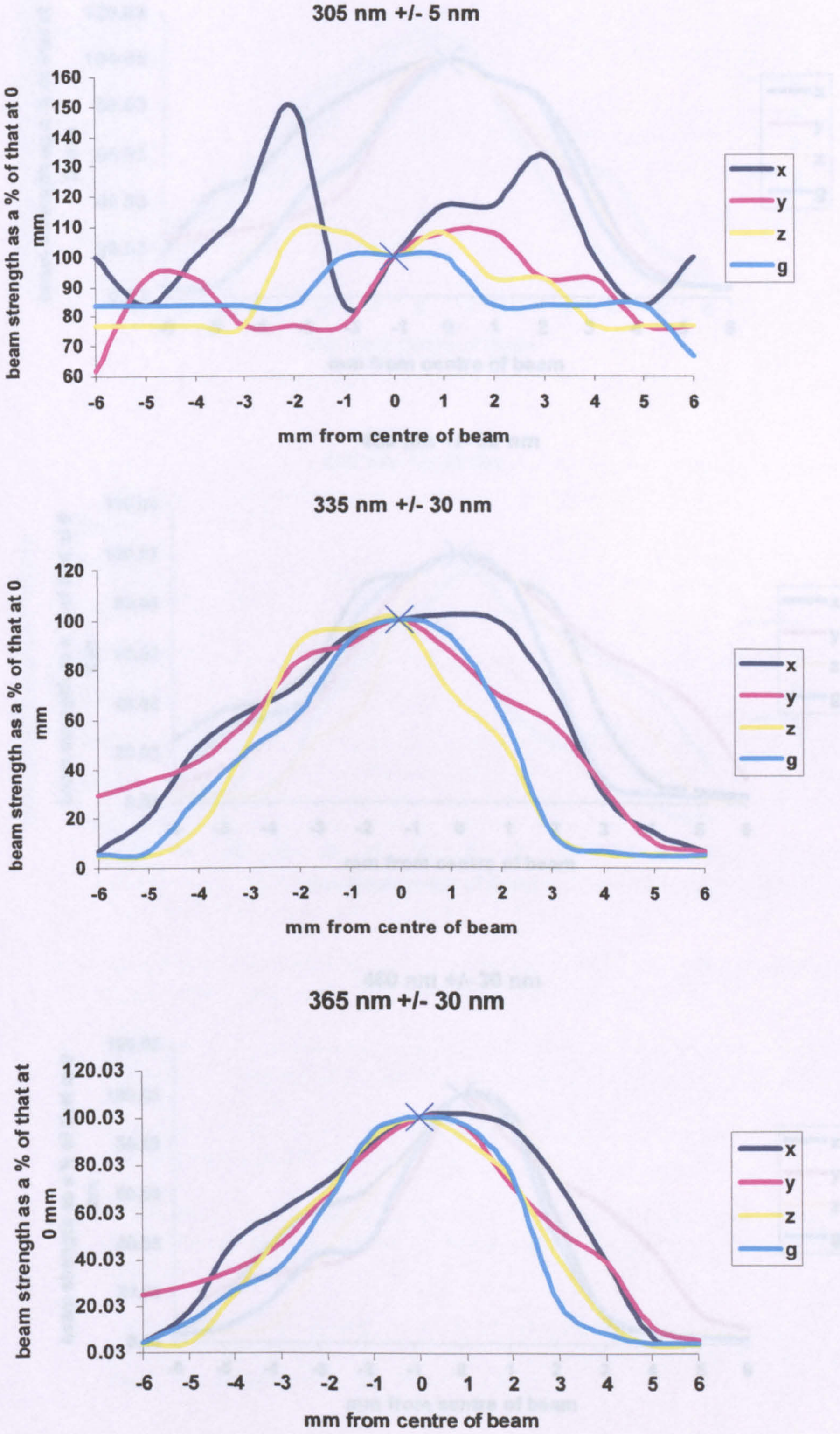
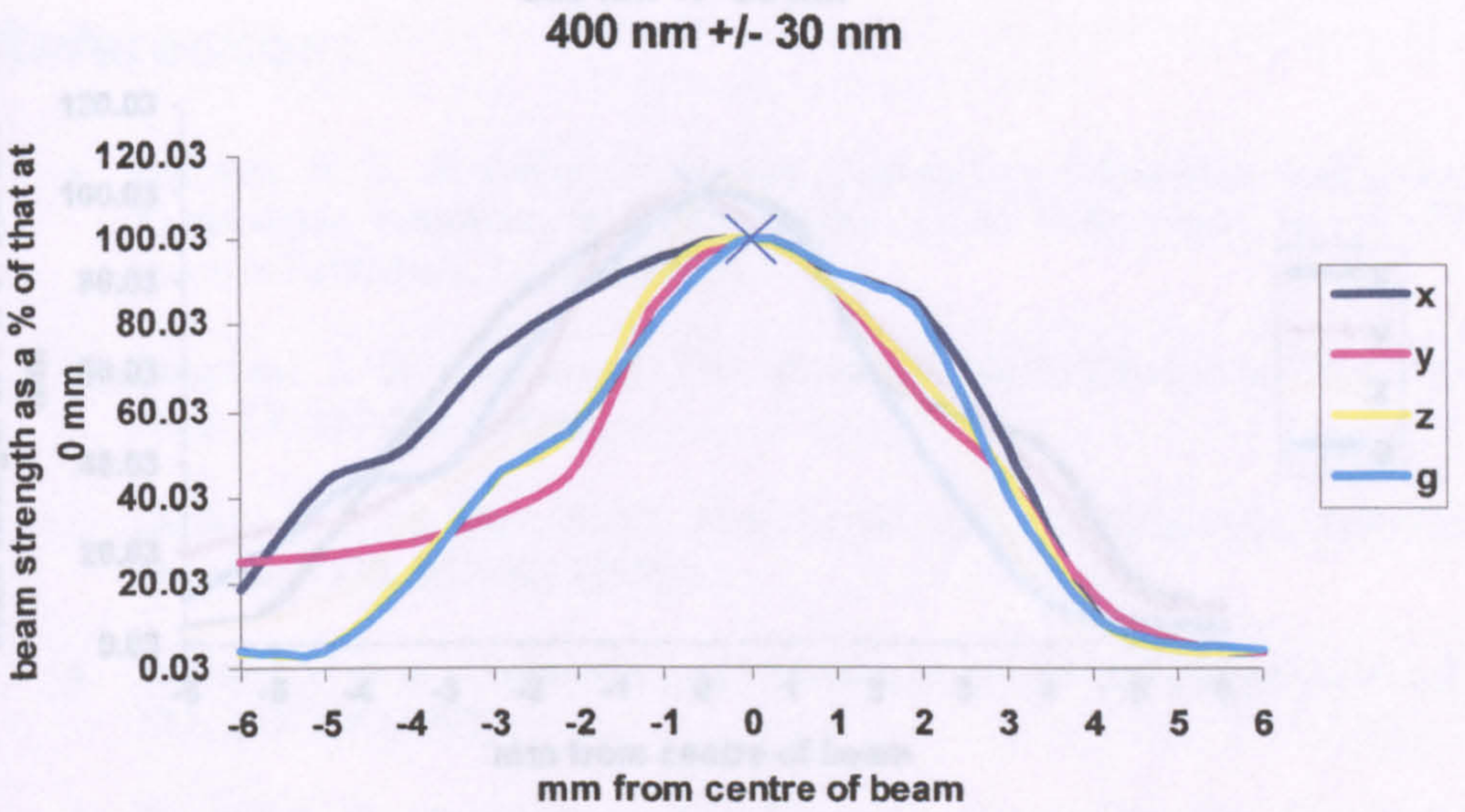
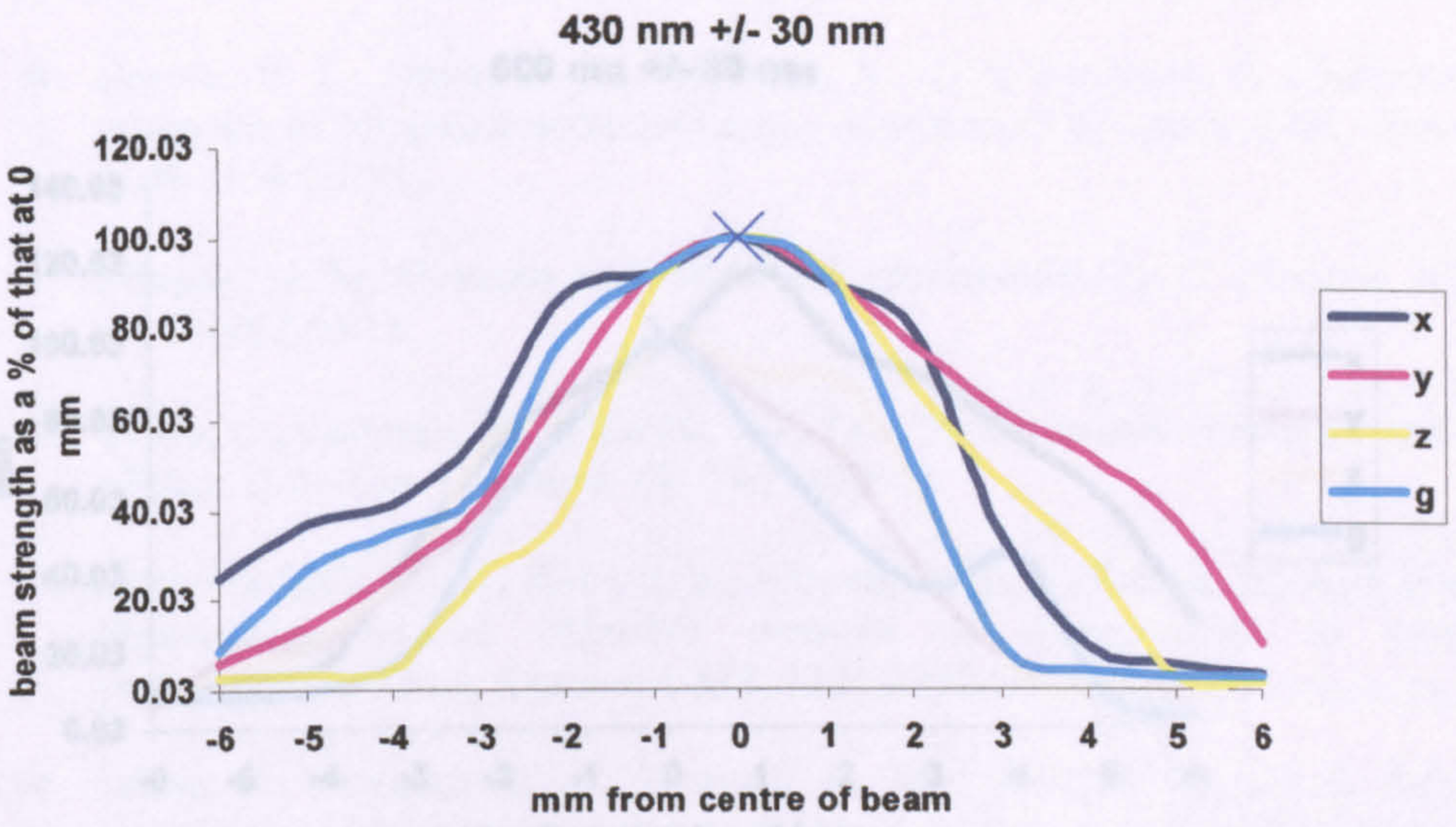
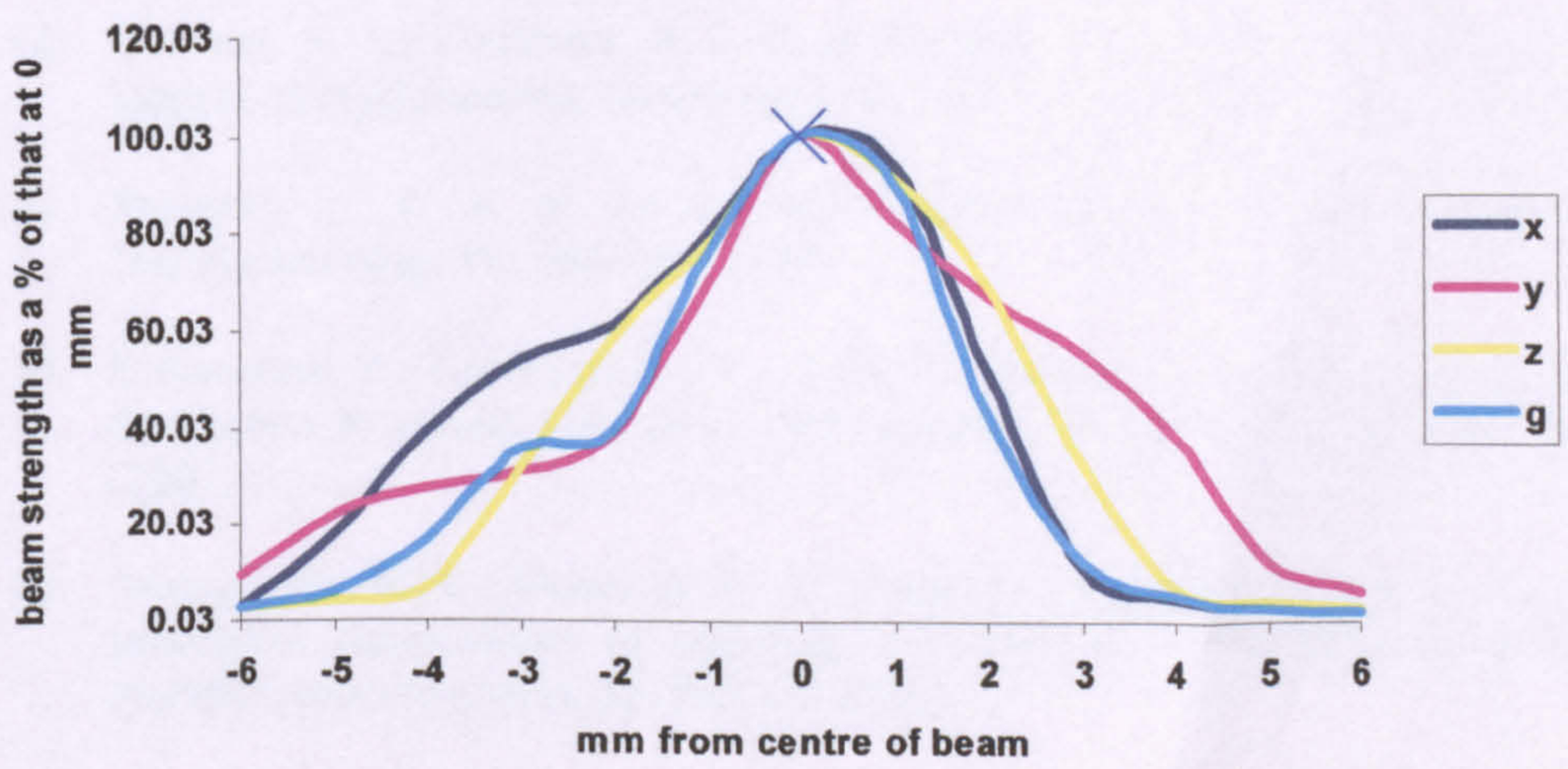


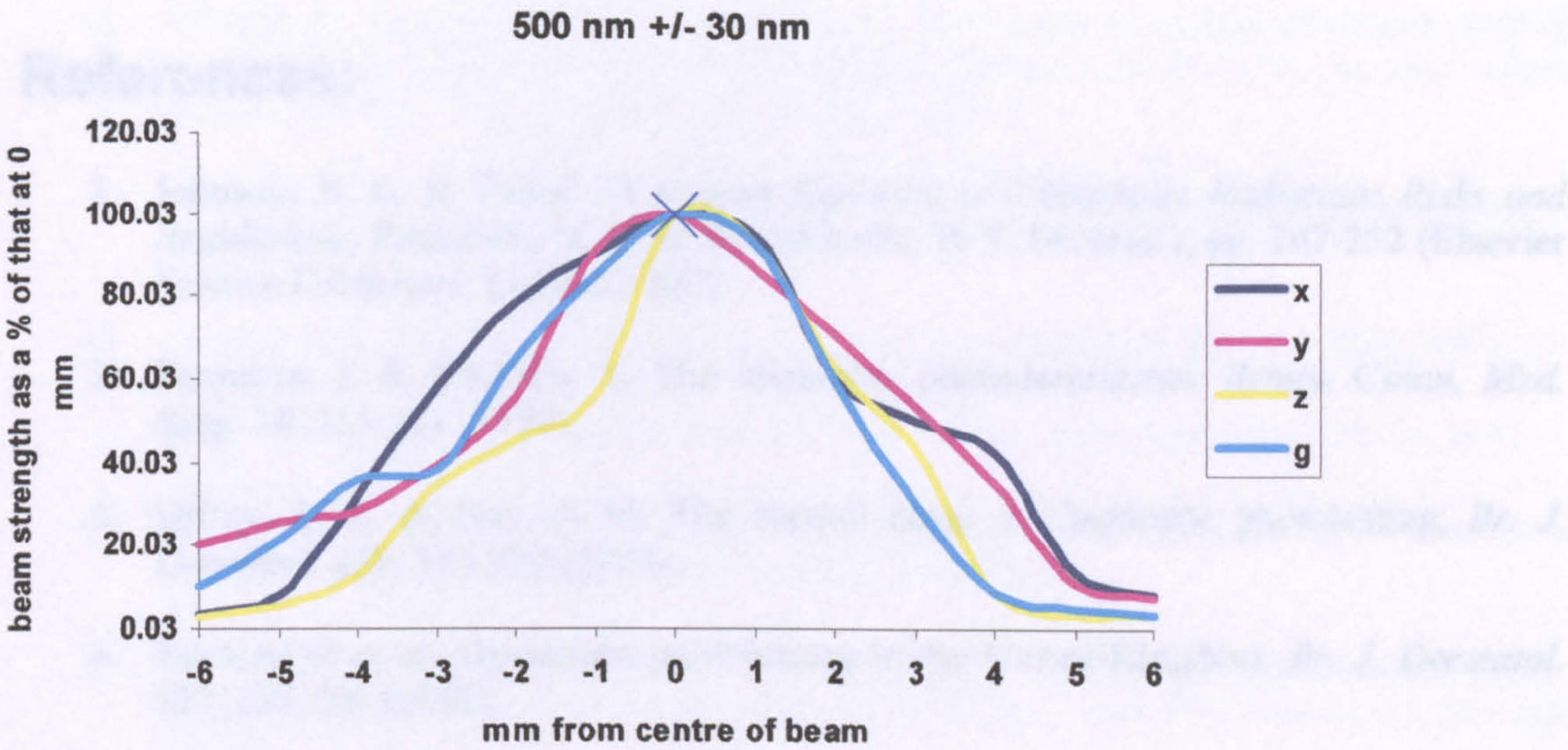
Figure 3A2.3 Beam uniformity of monchromator 3

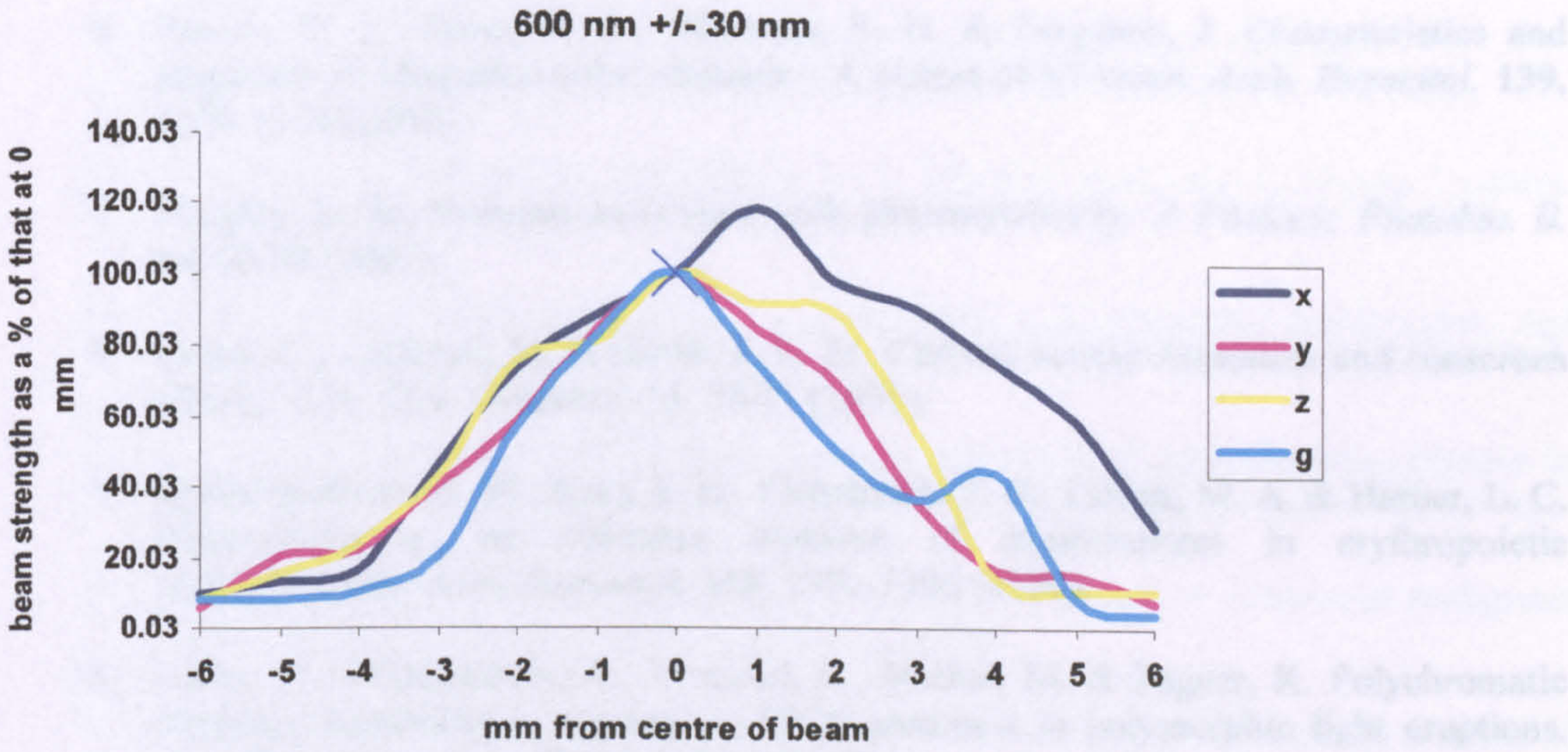



400 nm +/- 30 nm
beam strength as a % of that at 0 mm
120.03
100.03
80.03
60.03
40.03
20.03
0.03
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
mm from centre of beam
x
y
z
g


430 nm +/- 30 nm
beam strength as a % of that at 0 mm
120.03
100.03
80.03
60.03
40.03
20.03
0.03
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
mm from centre of beam
x
y
z
g


460 nm +/- 30 nm
beam strength as a % of that at 0 mm
120.03
100.03
80.03
60.03
40.03
20.03
0.03
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
mm from centre of beam
x
y
z
g


500 nm +/- 30 nm
beam strength as a % of that at 0 mm
120.03
100.03
80.03
60.03
40.03
20.03
0.03
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
mm from centre of beam
x
y
z
g


600 nm +/- 30 nm
beam strength as a % of that at 0 mm
140.03
120.03
100.03
80.03
60.03
40.03
20.03
0.03
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
mm from centre of beam
x
y
z
g

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Chapter 4

Protection of photosensitive skin from optical radiation hazards

Management of photosensitive skin disorders with commercial cosmetic products

Summary

In this chapter the management of photosensitive skin conditions is discussed. Sunscreens are often used in conjunction with other therapies but conventional sunscreens provide little or no protection for patients sensitive to visible wavelengths[1,2]. Sunscreens developed in Dundee are available which afford protection into longer wavelengths [3]. However, these creams are not readily available and are thick and difficult to apply and wear and thus are not aesthetically acceptable. Results from an investigation of commercial makeup products for topical photoprotection are presented.

1. Introduction

The photosensitive patient can face a severely restricted quality of life if their adverse response to light is not suppressed. Photosensitive skin disorders can have a major impact on the lives of sufferers. Patients that suffer pain, itch and potentially life threatening allergic reaction to light [2] must avoid being exposed to the wavelengths of light that cause their skin to flare. Furthermore, the psychological impact of reddened, scaly skin, particularly on the face, is often severe, in some cases leading to suicide.

Without the correct diagnosis and treatment, patients may be limited to only being able to venture outside on dull, cloudy days. The most sensitive patients can, effectively, be left housebound by their condition.

Thus, the first step in treating a patient with a suspected photosensitivity skin disorder is for the patient to be referred to a specialist centre for diagnostic phototesting [4] (see chapter 5). This testing assists in diagnosis by defining the wavelengths that are involved in the reaction so that appropriate means of management can then be considered [5-8]. There are several strategies that are used to manage symptoms and allow photosensitive patients to lead as close to a normal life as possible.

Means of management

The management of photosensitive skin is a clinical challenge that often necessitates the use of a variety of approaches simultaneously. Light avoidance is unparalleled as a means of control of photosensitivity and is often the first line of defence [9,10]. However, complete avoidance is often not possible due to the wavelengths involved in the sensitivity and the patient's lifestyle. Nevertheless, some changes in lifestyle can be sufficient to prevent an adverse response from occurring in some patients.

For example, a patient with mild UVB sensitivity only will have no problems in the winter months but will have to avoid exposure to summer sun between the hours of 11 am and 3 pm. A patient such as this would most likely be able to cope by using high

factor conventional sunscreen and/or staying in doors on bright days, or covering up as much exposed skin as possible with clothing [5,9].

The protection afforded by clothing is affected by several factors: fabric porosity, type, colour, wear, wetness, weight and thickness [11]. Dark coloured, close weave fabrics are best for UV protection [5]. Clothing labelled with an ultraviolet protection factor (UPF) are available from shops, particularly those specialising in outdoor pursuit equipment. Adding UV absorbers to the fabric can also further enhance the UPF [11]. There is a standardised *in vitro* method of testing textiles for their UPF protection and independent testing laboratories have been shown to give good agreement in their results [12]. However, one study found that the *in vivo* UPF is significantly different to the *in vitro* UPF provided by clothes [13]. Thus, patients sensitive to UVB should choose clothes with a high UPF or dark coloured, close weave clothes in order to maximise the protection offered by their garments.

UVA sensitivity is more complicated to manage by means of avoidance. UVA is transmitted through glass where UVB is not [9,14], including car windscreens which transmit from 380 nm [15] so patients may have to protect themselves when indoors. UV attenuating museum film can be applied to car, house and office windows [15,16]. Clothing and avoidance are also important for these patients although they will have to be more fastidious than those sensitive solely to UVB.

Sunscreens formulated to include UVA protection may have a role to play for these patients as well. Sunscreen products have two modes of action: chemical and

physical [2]. Chemical sunscreens absorb specific absorption bands, and hence a combination of chemical filters are often used in commercial preparations [9,17].

Physical sunscreens (sometimes marketed as 'sunblocks') are opaque formulations that contain inorganic powders that scatter or reflect UVR [2]. Titanium dioxide is a white pigment that is used in cosmetics, paint, textiles and ceramics and is commonly used in physical sunscreens, as is zinc oxide [17] and iron oxide [18]. The protection afforded by these particles depends on the size of the particles and the thickness of the layer applied to the skin [2,19,20]. Both these powders are white and a thick coating is required for adequate protection [17]. This can lead to patients rejecting these preparations on aesthetic grounds [1]. A study has shown that patients apply more chemical sunscreen than physical sunscreen (⅔^{rds} of the amount of chemical sunscreen) due to cosmetic unacceptability of physical blocks [21]. Reducing the size of the particles can enhance the cosmetic acceptability of physical sunscreens; microfine particles are now commonplace [2,17,22] in broad-spectrum sunscreens.

Over the counter sunscreens are generally formulated to protect against the erythemal effects of UVB and the ageing effects of UVA. In order to give consumers a guide as to the level of protection provided by a sunscreen, the sun protection factor (SPF) exists. SPF testing is stringent, with standards requiring *in vivo* testing [23,24]. However the SPF of a product gives no indication of the UVA protection afforded [25-28] because the SPF is calculated using the erythemal action spectrum and is therefore an indication of burn protection only. As UVB has the greatest potential for causing erythema, sunscreen users are able to spend a much longer period of time in the sun without experiencing discomfort, and hence receive a large dose of UVA [29].

Concerns regarding chronic exposure to UVA [25,30,31] have meant that during the past decade many sunscreens that include UVA filters have become available [27] but there is no standardised method of defining the amount of UVA protection afforded by a sunscreen product [2,25,27,32].

Furthermore, some sunscreens that claim UVA protection can have transmittances that vary from 6% to 52% [33]. In particular, one product that claimed a UVA protection factor of 15 was found in practice to be only factor 4 [34]. Instead of claiming an UVA protection factor, Boots the Chemist, the UK's largest producer of sunscreens, have developed their own star rating system for UVA protection, based on the ratio of the total absorption of a product in the UVA to that in the UVB [35]. A five star product has a UVA ratio $0.8 \geq 0.8$ and would therefore be suitable for most UVA sensitive patients.

Of further concern for the UVA sensitive patient seeking to identify a suitable product is the fact that chemical sunscreens have been reported to cause allergic contact and photoallergic contact dermatitis [2,36]. There is one reported case of a CAD patient being hospitalised after severe exacerbation of his condition by exposure to a sunscreen [10]. This is a rare case and there are several reports in the literature of the scale of this problem. Two of the most comprehensive studies analyse 15 years' of data. Darvay *et al* analysed the patch test results of 2715 patients with suspected photosensitivity. 49 patients had a total of 75 positive allergic contact reactions, 51 of which were due to UV filters. 80 photoallergy reactions in 62 patients (34 with underlying photodermatosis) were recorded, of which UV filters accounted for 52 positives. Darvay *et al* conclude that allergic contact and photoallergic contact

reactions to UV filters are rare but patients with photodermatoses are at increased risk of developing photoallergy [37]. The other comprehensive study analysed the patch and photopatch test results of 402 patients with suspected photosensitivity. 80 (47 with underlying photodermatosis) patients had allergic contact and/or photoallergic contact dermatitis to one or more UV absorbers [38]. It is notable that the Darvay *et al* study report lower rates of skin sensitisation to UV filters but this may be due to the fact that they included a larger sample in their survey and also may reflect different criteria for patch and photopatch testing patients. Other studies confirm that sunscreens may be problematic for photosensitive patients [39,40].

Chemical sunscreens were thought to be absorbed into the stratum corneum where there are no viable cells, however, the fact that sunscreens can cause phototoxic and photoallergic reactions indicates that some sunscreen must be absorbed into viable skin where UV filters may react with endogenous proteins and lead to photosensitisation [2]. Hence, physical sunscreens are considered a better option for photosensitive patients [36] but titanium dioxide and zinc oxide both have absorption bands in the UV (up to 400 nm) and may therefore act like chemical sunscreens. However, there are no reports in the literature of sensitisation to physical sunscreens [2].

Of further concern are problems of photodegradation of UV filters. Irradiation of UV filters with UVA in lab conditions has been shown to lead to break down of such filters [41] and thus becoming unstable [42]. This can lead to reduction of protection by 50-60% [31] and emphasises the need for sunscreens to be reapplied frequently [9].

Thus, the problems encountered by those photosensitive to UVA are in identifying a suitably protective product and one that will not lead to sensitisation of the skin. Photosensitive patients with defined UVA sensitivity should choose a sunscreen recommended by their treatment centre or a broad spectrum physical sunscreen, taking care to avoid any ingredients to which they know they are sensitised [10].

Visible light sensitivity is the most complicated to manage because exposure to visible wavelengths is practically unavoidable. Clothes and wide brimmed hats are commonly used. Figure 4.1 shows a solar urticaria patient who attends the photobiology unit regularly. His typical dress for leaving the house even on a winter's day includes the hat and gloves pictured.

Figure 4.1: A severely sensitive solar urticaria patient in typical photoprotective clothing. Picture used with permission.

There are numerous publications suggesting topical photoprotection as a management strategy for photosensitive skin [1,2,5,9,18,30,43,44⊗]. Chemical sunscreens are of limited therapeutic benefit for the photosensitive patient whose action spectrum extends into the visible spectrum [2]. Zinc oxide and titanium dioxide are used in conjunction with UV filters to enhance protective effect above 370 nm [17]. Certainly these powders reflect mainly the longer UVA wavelengths [30] and the addition of pigments to sunscreens improves the protection in the visible region [22]. There are few products except opaque, physical sunscreens that offer sufficient protection into the visible spectrum for visible sensitive patients [18].

Moseley *et al* developed a range of creams, known as the Dundee creams that offer significant protection against visible light [3]. These creams contain titanium dioxide as well as other, coloured pigments. Using an action spectrum of a patient with PCT, a protection factor was defined for these creams for photosensitive patients, and they are routinely prescribed for management of photodermatoses [45].

Dundee creams are available in three colours: beige, coral and coffee colours. In order to achieve an acceptable skin match for a person with skin type 1-2, some coral must be mixed with beige. This elaborate process is time consuming and awkward for patients and it is difficult to achieve the desired colour. Patients describe these creams as being uncomfortable to wear as a thick layer must be applied, which means that the skin can become very hot as pores are blocked and the creams often rub off onto and stain clothes.

⊗ Suggest SPF factor 20

Chemical means of protection

In severe cases of photosensitivity, the protective measures detailed above may not be sufficient or suitable to reduce a patient's reaction to a tolerable level. In these cases more drastic measures are necessary. Perhaps the least extreme medical intervention is the use of oral beta-carotene as a photoprotective agent in EPP [5,46]. Apart from giving the skin a slightly orange colouration, there are no other known side effects from this therapy and it is therefore the treatment of choice in EPP [47]. Beta-carotene does not work by absorbing UVR as it does not reach sufficient concentration in the skin, therefore it must work by an alternative mechanism in EPP patients [48]. This therapy has been tried for other photosensitive skin disorders but often no clinical improvement is seen [45,49], probably due to the fact that it does not work as a photoprotective agent [48]. As a last resort EPP patients can be given allogenic bone marrow transplants but this carries with it a high associated mortality [45].

Topical corticosteroids can reduce redness and inflammation of the skin. They can also be given orally if symptoms require greater control [50]. However, systemic corticosteroids if taken over a long period of time, have associated side effects, such as osteoporosis and increased susceptibility to opportunistic infections [51] so short courses of treatment are often preferred.

UV treatment is common for managing solar urticaria [52] and PLE [2,5], either used on its own or in combination with oral steroids [53]. There are two modalities to this treatment: desensitisation and immunosuppression. Patients sensitive to summer sun can have a course of UVB phototherapy in spring to desensitise the skin through what

is thought to be a combination of immune suppression, tanning and thickening of the stratum corneum [54]. PLE has been successfully treated with TL01 or PUVA in the springtime [55]. Those with a well-defined, limited action spectrum can be treated with wavelengths that do not provoke their adverse skin response as an immunosuppressive treatment. UV phototherapy does carry with it an increased risk of skin cancer and so treatments should be limited to therapeutic necessity [56-59].

Clinical experience has provided evidence of further chemical ways to manage photosensitivity. Low doses of anti malarial drugs can also be used to control PLE [2,36] and antihistamines are effective in suppressing the urticarial response in many patients with solar urticaria [2,43].

An even more rigorous means of management is immunosuppressive therapy. This is reserved for patients whose conditions are severely restrictive. Cyclosporine [49,60] and azathioprine are used as immunosuppressive agents in dermatology [51]. The latter has been available since the 1960's and is used for a variety of dermatologic conditions [61]. Immunosuppressive therapy is commonly used to manage debilitating CAD [2,10,50,62,63] and PLE when the symptoms are disabling [2,36]. However, this type of therapy carries with it the risk of potentially serious long and short-term side effects, including renal toxicity, gastrointestinal disturbances causing nausea and vomiting, increased susceptibility to opportunistic infection, neurological disturbances, reproductive toxicity and, most worryingly an increased risk of malignancy [51].

It is clear that medical interventions (except beta-carotene) carry with them side effects that should be avoided. One of the cheapest, most effective, and certainly the least intrusive means of management is topical photoprotection [5].

Cosmetics for photoprotection

The success of the Dundee creams but their limitations in aesthetic terms prompted this investigation to evaluate other products that could potentially be used for photoprotection into the visible spectrum. It has been proposed that coloured compounds are good at absorbing long wavelengths [9]. Commercial, cosmetic preparations (foundations) are used by many women to cover blemishes and imperfections of their skin. These products are pigmented so could afford photoprotection.

Foundations are widely available, vary in price and there are also a wide range of colours and consistencies available. Thus, if these products afford protection in the visible part of the spectrum, patients would have a much wider choice of products to protect themselves. The availability of many different colours means that patients could match their skin tone with relative ease and without any requirement for blending colours. Many foundations are hypoallergenic and also contain sunscreens.

Of particular interest is the possibility of using makeup products for photoprotection of patients photosensitised due to PDT drugs. PDT is a treatment modality that is growing in popularity and patients that take systemic photosensitising drugs can be rendered photosensitive for up to 3 months, which, in cases where the treatment is

only palliative can be a factor that prevents the patient from consenting to the treatment. If patients were required to wear makeup after their treatment but could otherwise lead a normal life then more people may consent to the treatment.

To my knowledge there are no published studies of the transmission spectra of commercial makeup products into the visible part of the spectrum. Hawk *et al* included Covermark* in their study and found it to have low transmittance up to 650 nm (13% maximum for all shades tested and wavelengths stated) in 1982 but suggested that men would not tolerate wearing this makeup [1]. Cosmetic science has advanced during the years since that study and the fashion is now for makeups to cover imperfections but look natural. It is likely that men would be more comfortable using these modern products than Hawk *et al* suggested they were using Covermark.

Testing photoprotective efficacy

There are two ways to test the protection offered by a product

(1) *in vivo* testing whereby the protection is defined as the ratio of the dose required to cause minimal erythema on protected skin to the dose required to cause minimal erythema on unprotected skin

and

(2) *in vitro* analysis of the transmittance of the product.

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* A commercial preparation

From *in vitro* measurements, the SPF is defined as

$$SPF = \frac{\sum_{290}^{400} E_\lambda S_\lambda \Delta\lambda}{\sum_{290}^{400} E_\lambda S_\lambda T_\lambda \Delta\lambda}$$

Equation 4.1

Where E_λ is the CIE erythemal effectiveness for radiation at wavelength λ [64]

S_λ is the solar spectral irradiance at wavelength λ

T_λ is the transmission of the sample at wavelength λ

This expression was used by Moseley *et al*[3] to create a photosensitivity protection factor from *in vitro* tests by replacing E_λ with the action spectrum of a patient with PCT. This action spectrum was calculated from the results of this patient's phototesting at 305 ± 5 nm and seven other wavelengths ± 30 nm. This calculation assumes that monochromator phototesting can be used to derive an action spectrum for a photosensitive patient. This, however, is not necessarily the case, as shown by work carried out in relation to the current investigation and discussed in chapter 5.

SPFs quoted on commercially available sunscreens are based on *in vivo* tests.

There have been many studies conducted looking at the correlation between *in vivo* and *in vitro* protection factors derived from sunscreens [65]. Although it is generally accepted that *in vivo* testing is the most reliable way to determine the protection that a sunscreen will give, it is not always possible. Normal skin is not sensitive to visible

light so irradiation times would be impractically long for evaluating the protection available at these wavelengths. A similar problem has been encountered when testing products for their UVA protection [34] and explains why there is no standardised test for UVA protection. Several studies suggest alternative means of deriving protection factors for UVA and broad-spectrum sunscreens. Volunteers have been given psoralen in order to test the protection factor of UVA sunscreens, however, this method produces a false action spectrum in the patient and the results are therefore biased towards UVA [22]. Photosensitive patients have been suggested as models for *in vivo* testing [22,28] but these results would depend on the action spectrum of the individual. This varies between and within diseases.

Thus *in vitro* testing is the best available option and also removes the need to expose volunteers to acute exposures of high dose UV [32] and any uncertainty due to errors associated with MED determination [66]. A substrate then has to be chosen for the product. Previous groups have used human epidermis from recently deceased cadavers [19], or excess tissue removed during breast reduction surgery [26]. Results have been shown to be reliable when comparing *in vivo* and *in vitro* SPF results from human skin [26]. However, this substrate was not available to the department and would have proved costly to acquire.

Artificial substrates are available. Diffey [67] first used Transpore tape as a substrate. This is a surgical tape and has dimples in the surface, thought to mimic the topography of human skin. This tape is cheap and readily available and good agreement can be gained when comparing *in vivo* and *in vitro* results [35]. Some studies criticise the use of Transpore tape due to differences between *in vivo* and *in vitro*

results, for example, Kelley *et al* were unable to match *in vitro* SPF's with those quoted (from *in vivo* testing) on some sunscreen products [65]. They were, however, using an UVB radiometer to measure the transmittance of the samples. This can give large errors due to the specific wavelength sensitivity of the the radiometer [68].

Labsphere have developed a glycerine based substrate known as 'Vitro Skin' that mimics the surface tension, pH and topography of human skin. Studies suggest that the correlation between *in vivo* tested SPF's and *in vitro* tested SPF's are 'excellent' when testing is done with Vitro Skin [35]. This substrate, however is expensive and complicated to use as it requires hydration prior to use and can only be kept for a limited amount of time once hydrated.

2. Methods and Materials

During April 2004, twenty-five makeup samples were collected from high street stores in Dundee. Different colours were collected in order to evaluate the difference that pigmentation would make to the protection offered. High end (expensive) samples were chosen, as well as cheaper products. Table 1 lists the manufacturers, names and prices of the products per 100 ml. Dundee creams supplied by Tayside Pharmaceuticals were also included as they are the only products currently available for photosensitive patients.

The method used was first described by Diffey and Robson in 1989 [67]. Samples were spread onto the non-adhesive side of Transpore surgical tape at a concentration of 2

$\mu l cm^{-2}$ *using a gloved finger. The samples were then allowed 20 minutes to dry [69] and used within 2 hours of preparation.

Eight measurements were made per 48 cm^2 (one spread) of sample by attaching jigs consisting of 8 circular apertures of 1 cm diameter to the adhesive side of the tape. Blank controls were made similarly but with no sample spread on the tape. The eight samples from each spread were irradiated in turn with xenon arc lamp, filtered for infrared radiation (IR) with an $H_2SO_4 \bullet CuSO_4$ solution and a cut on filter (GG375, Schott). The GG375 filter was used to exclude any possible photodegredation effects due to the large amount of UVR present in an unfiltered Xe lamp. This is similar to the approach used by Gróf et al [70].

The lamp was allowed at least 15 minutes to stabilise prior to commencing measurements. The transmission through the samples was recorded with a Bentham DM150 double grating spectroradiometer. A flat plate quartz diffuser made up the input optics for the monochromator. The detector is a cooled (-20°C +/- 1°) photomultiplier tube. The transmission of the sample at λ nm is the ratio of the photocurrent at wavelength λ on blank tape to the equivalent photocurrent with a product applied to the tape. The photocurrent was recorded at 5 nm intervals from 400 to 800 nm. Two independent measurements were carried out for each product tested.

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* The volume of sunscreen needed to fill all the grooves responsible for primary epidermal surface lines on $1 cm^2$ of skin surface, to produce a featureless surface, is 1-2 µl [66].

3. Results

Table 4.1 shows the makeup names, maker, cost per 100 ml and transmission at 100 nm steps across the range shown. The transmissions at 630 and 652 nm are also shown, as these are wavelengths routinely used in PDT. Patients are sensitised to these wavelengths using either systemic or topical preparations before treatment with the appropriate source in PDT.

The mean coefficient of variance (CoV) of each sample is also shown to indicate the errors inherent in the measurement technique. The CoV is the ratio of the standard deviation of the measurements to the mean measurement at each wavelength interval and can be regarded as the uncertainty in each measurement. The mean variances for all samples range from 6.9% to 22.6%, mean 12.9%, median 11.7%. These errors represent the problems inherent in this method of *in vitro* testing. Spreading the samples on the tape has been shown to be tester specific [65] and also non-uniform [71], hence accounting for the variances in the samples. Two independent spreads and 8 measurements of each spread were done in order to reduce the error but at the prescribed concentration it was difficult to achieve an even spread with some samples. Hence, in practice, greater amounts of the makeup samples may be used in order to achieve even coverage on the skin. This would result in greater protection being afforded to the user.

Figures 4.2 to 4.8 show the makeups from the different manufacturers represented in graphical form. Error bars are shown on selected samples at 20 nm intervals in order to preserve the clarity of the information represented on the graphs. It is clear that

within one brand and type of makeup, the darker colours do offer more protection, but colour is not a good indicator of the protection offered. Table 2 lists all the products average transmission over the 400nm range tested, in ascending order. Max Factor Seamless Makeup in sand is the best protector across the wavelength range and would be the best choice for protection of photosensitive individuals who require protection over the full range of wavelengths. It is notable that this makeup and Clinique Dewy smooth anti ageing makeup in neutral and Max Factor Seamless makeup in porcelain offer more protection than Dundee coffee, which is the most protective Dundee cream.

Table 4.1: Makeup brands and colours, cost per 100 ml and transmissions at selected wavelengths

Manufacturer/Brand	Makeup name	Colour	Cost (£)/100 ml	Transmission at stated wavelengths (nm)							CoV (%)
				400	500	600	630	652	700	800	
Clarins	True radiance foundation	Tender gold 10	39	23%	25%	32%	33%	35%	37%	41%	9.0
Clarins	Multi-matte foundation	Tender ivory 07	67	28%	30%	34%	34%	35%	35%	36%	8.0
Clarins	Hydrating liquid foundation	Soft Ivory 03	65	17%	18%	23%	23%	24%	25%	27%	9.9
Clarins	Extra-firming foundation	Shell 05	47	11%	15%	20%	21%	22%	23%	26%	11.5
Clinique	Superbalanced makeup	Toffee	23	11%	14%	24%	26%	29%	30%	36%	22.0
Clinique	Superbalanced makeup	Ivory 03	23	6%	12%	19%	20%	21%	24%	29%	13.8
Clinique	Superfit makeup	Petal	57	15%	18%	25%	27%	28%	31%	37%	15.3
Clinique	Dewy smooth anti ageing makeup	Neutral	58	6%	9%	17%	18%	19%	21%	26%	16.0
Clinique	Superfit makeup	Beige	57	13%	17%	25%	27%	28%	31%	37%	12.4
Elizabeth Arden	Flawless finish bare perfection makeup	Mocha II 41	57	17%	20%	26%	27%	29%	31%	36%	10.8
Elizabeth Arden	Flawless finish radiant moisture makeup	Cameo 24	57	18%	22%	28%	29%	31%	33%	37%	20.4
Marks and Spencer	Flawless finish foundation	Ivory	43	13%	17%	25%	26%	28%	29%	34%	13.0
Marks and Spencer	Enhance line minimising foundation	Honey	30	5%	12%	20%	22%	23%	25%	30%	21.8
Marks and Spencer	Sheer finish foundation	Coffee	43	13%	25%	39%	41%	43%	47%	53%	6.9
Marks and Spencer	Flawless complex foundation	Sand	20	20%	29%	37%	39%	40%	42%	46%	7.5
Marks and Spencer	Flawless complex foundation	Honey	20	12%	27%	36%	37%	39%	40%	45%	9.9
Marks and Spencer	Autograph flawless finish foundation	Coffee	43	5%	9%	19%	21%	22%	25%	31%	7.7
Marks and Spencer	Sheer finish foundation	Ivory	43	16%	25%	34%	36%	37%	40%	46%	7.5
Max Factor	Seamless makeup	Sand	22	7%	9%	15%	16%	16%	17%	19%	15.9
Max Factor	Hyper smooth makeup	Natural	28	11%	15%	21%	22%	22%	23%	26%	6.9
Max Factor	Seamless makeup	Porcelain	22	10%	13%	18%	18%	19%	20%	22%	16.7
Max Factor	Lasting Performance	102 Pastelle	27	8%	12%	21%	23%	24%	27%	34%	16.7
Max Factor	Lasting Performance	Natural bronze	27	6%	9%	18%	20%	21%	24%	31%	22.6
No7	Radiant glow foundation	Almond 10	42	19%	23%	30%	30%	32%	33%	36%	11.7
No7	Radiant glow foundation	Beige 07	42	16%	20%	27%	27%	29%	30%	34%	17.9
Tayside Pharmaceuticals	Dundee cream	Beige	prescription	18%	27%	36%	37%	39%	42%	48%	7.15
Tayside Pharmaceuticals	Dundee cream	Coffee	prescription	5%	10%	18%	19%	20%	23%	28%	9.13
Tayside Pharmaceuticals	Dundee cream	Pink	prescription	13%	22%	29%	32%	33%	36%	42%	8.53

Figure 4.2: Transmittance of Clarins makeups

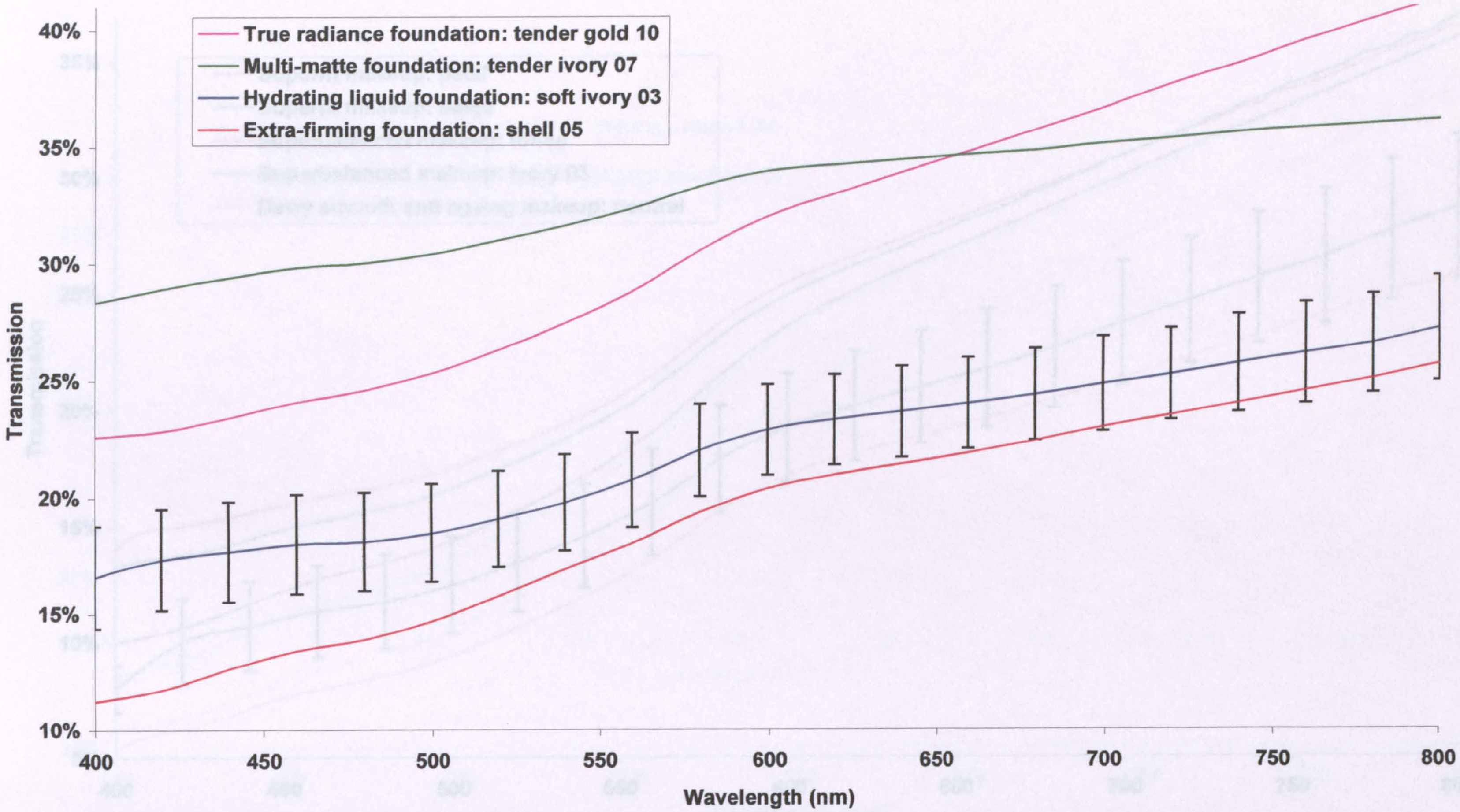

Figure 4.3: Transmittance of Clinique makeups

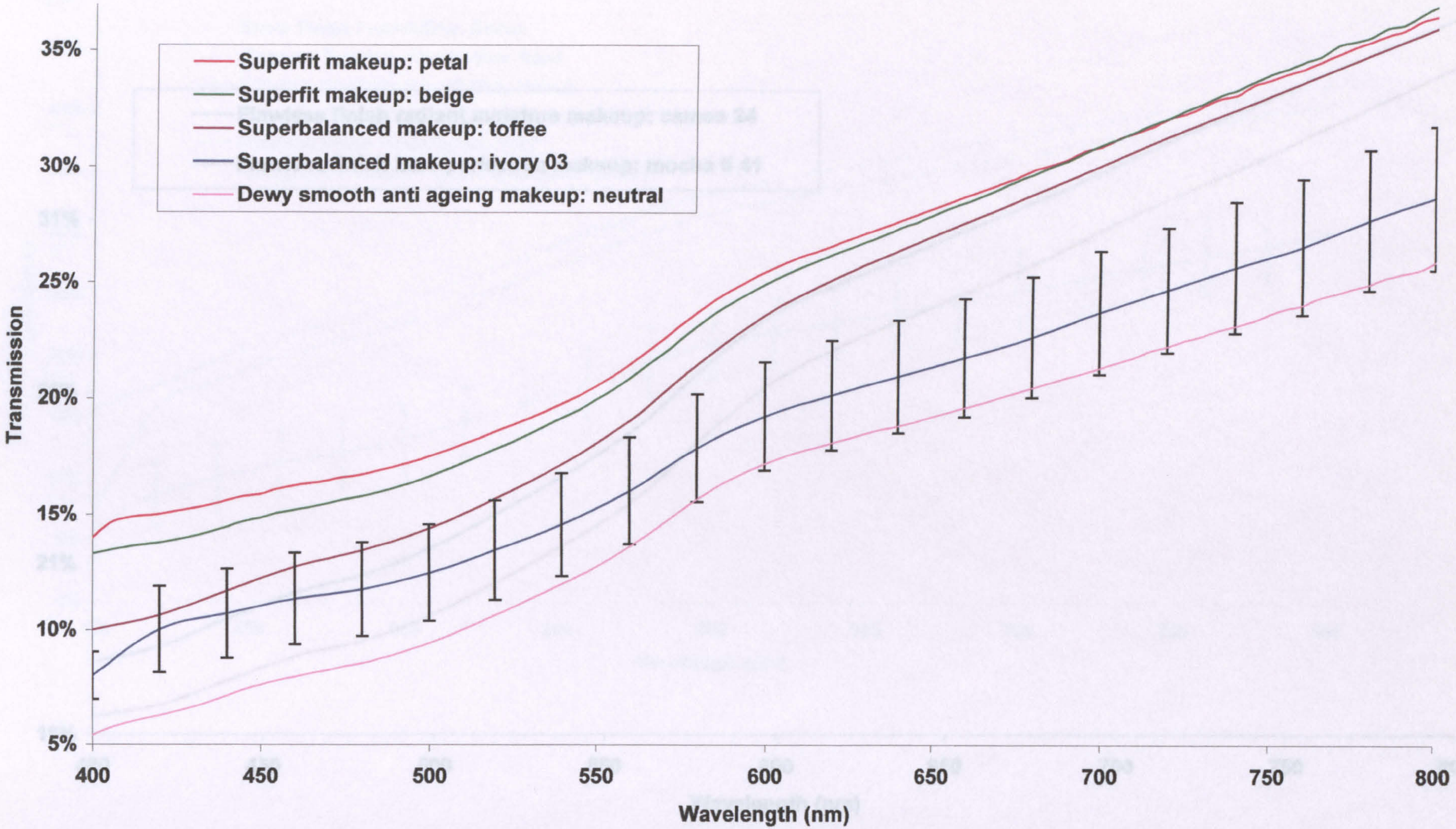

Figure 4.4: Transmittance of Elizabeth Arden makeups

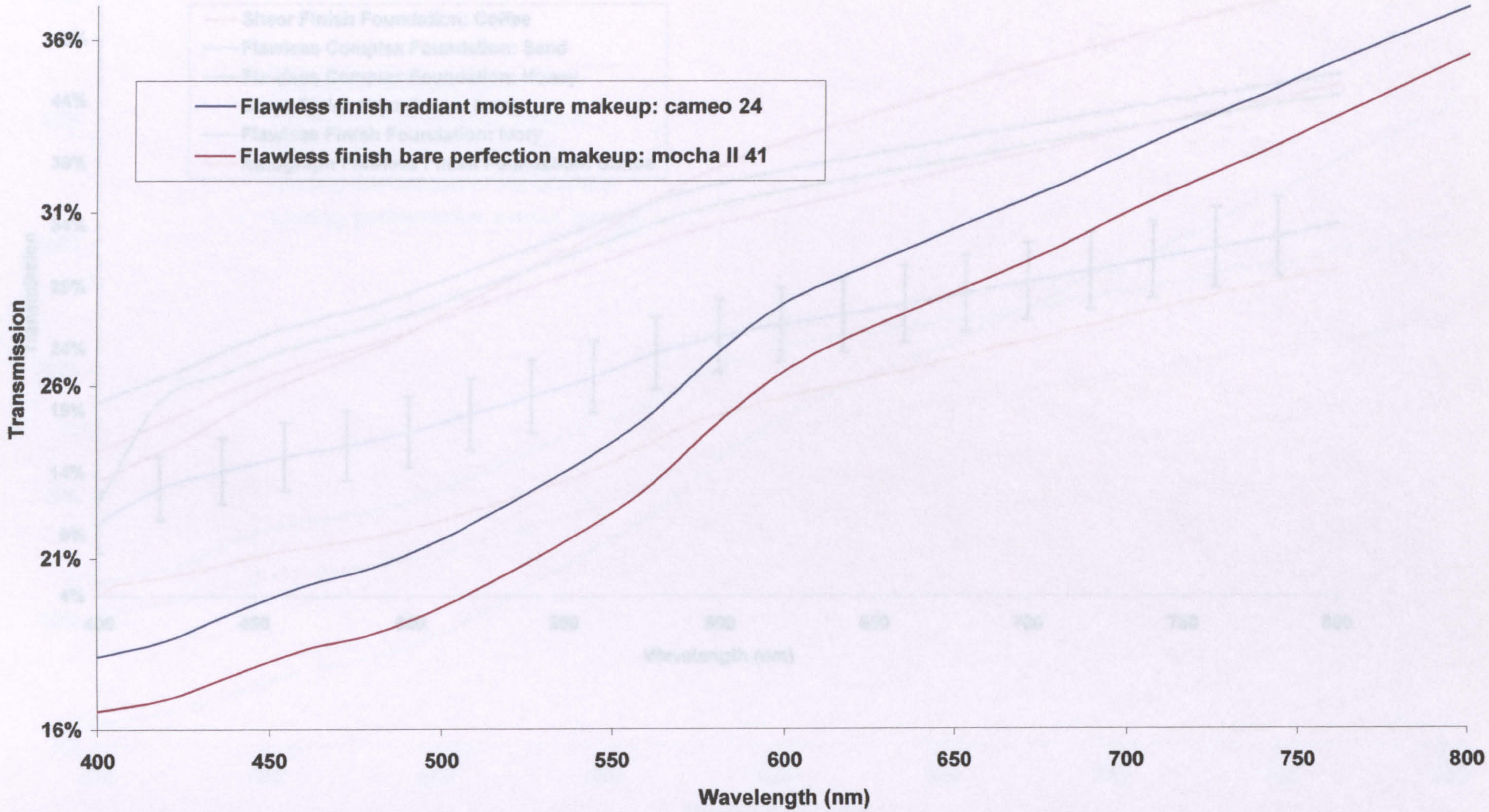

Figure 4.5: Transmittance of Marks and Spencer makeups

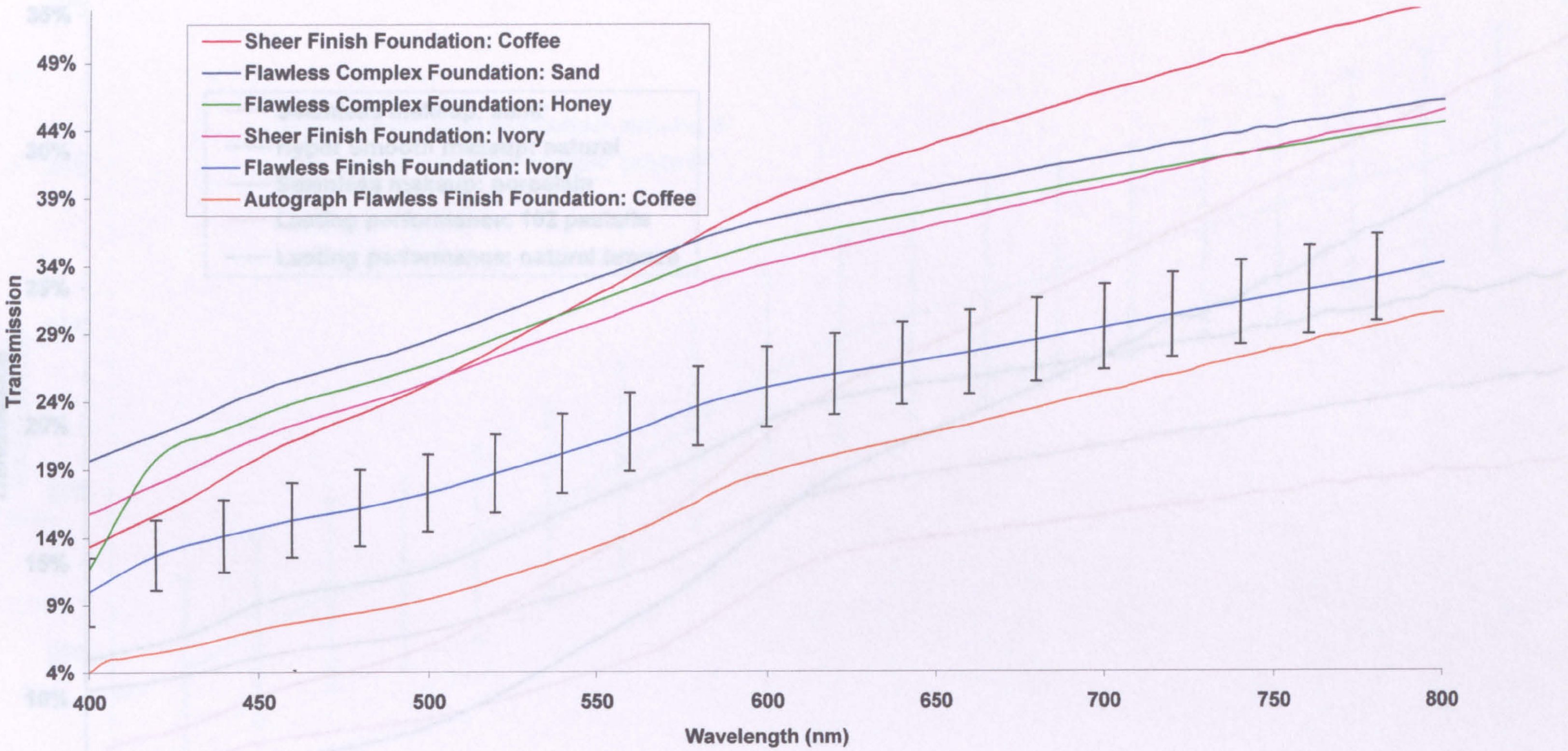

Figure 4.6: Transmittance of Max Factor makeups

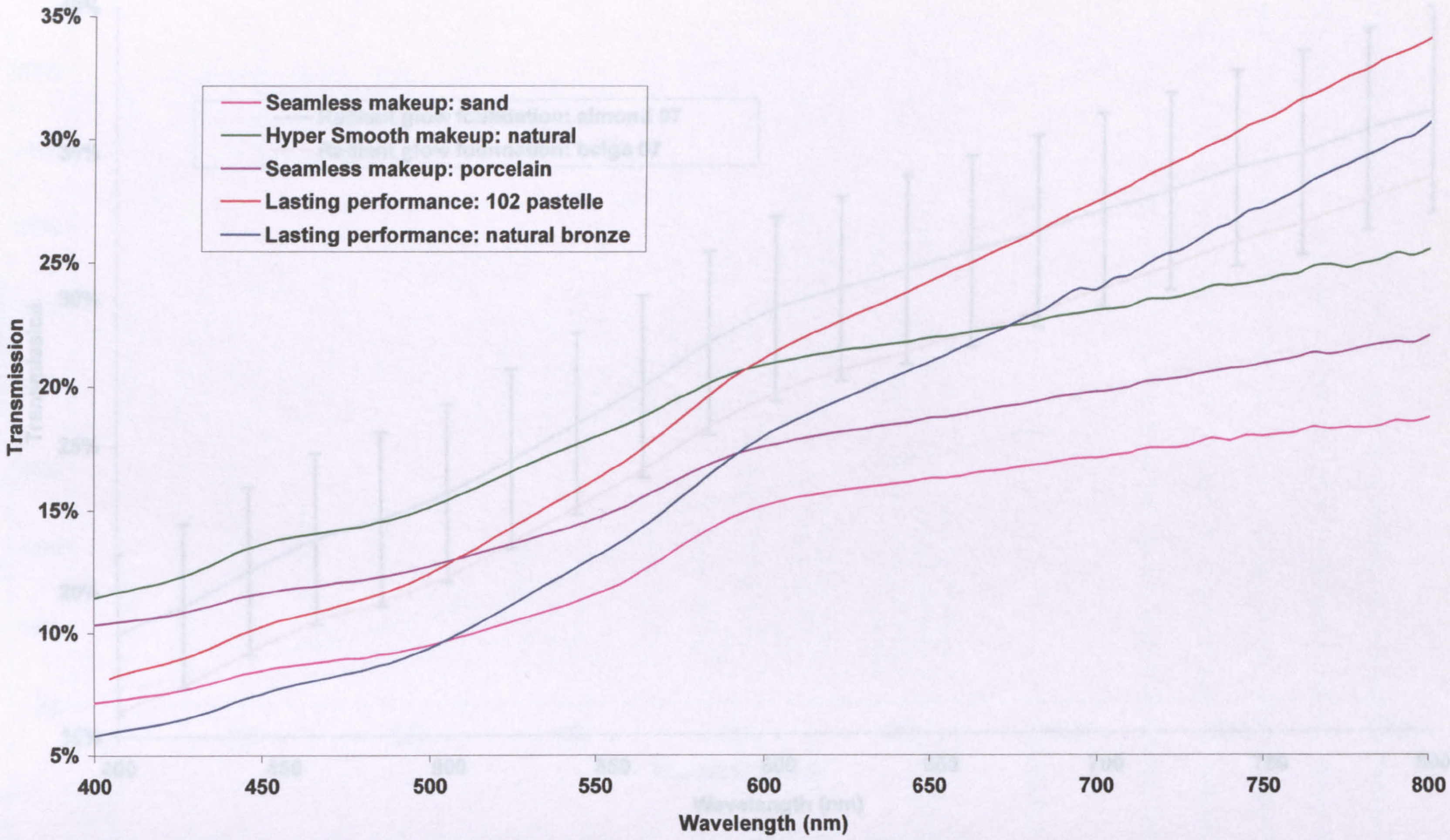

Figure 4.7: Transmittance of Number 7 makeups

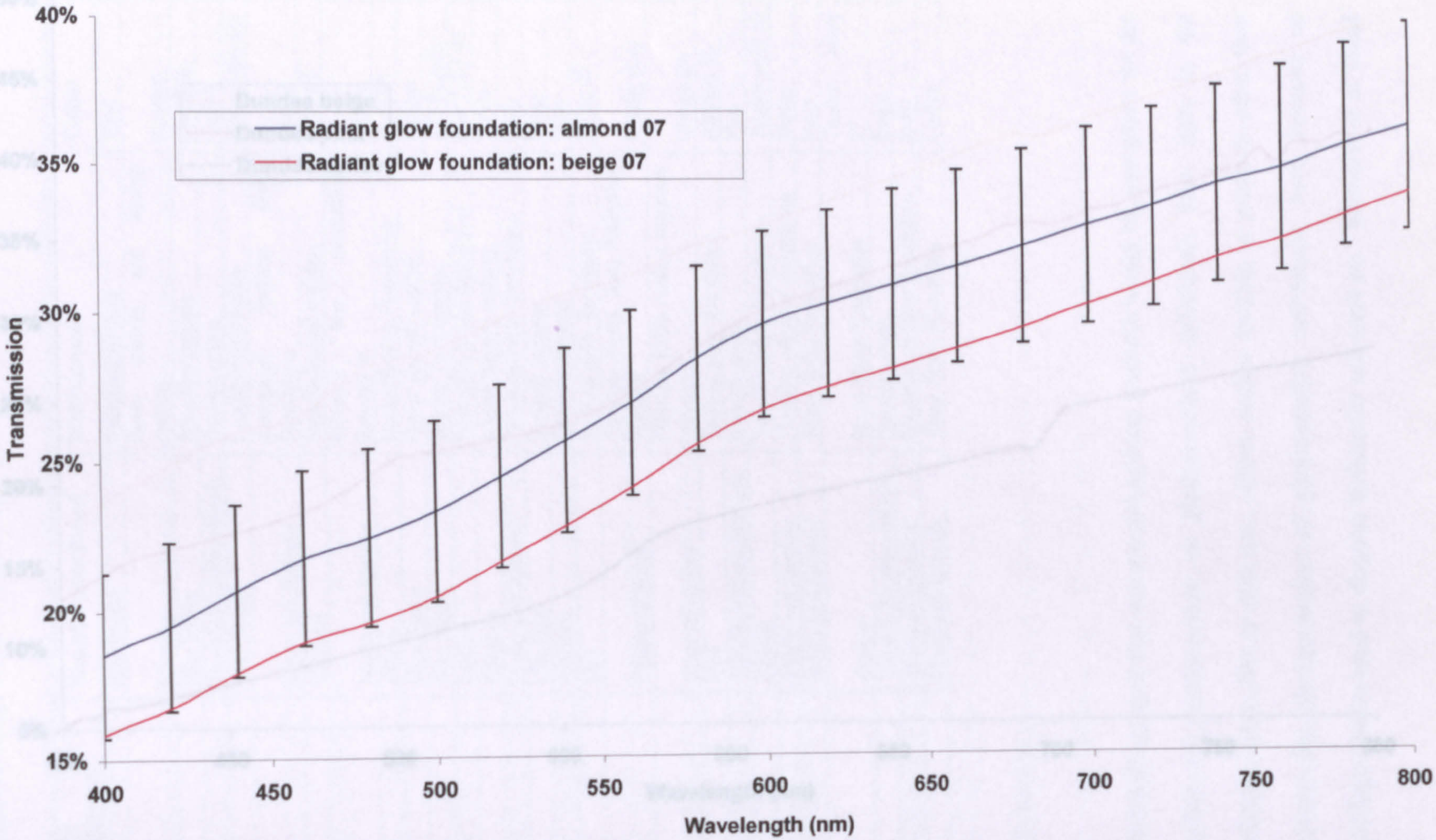

Figure 4.8: Transmittance of Tayside Pharmaceuticals creams

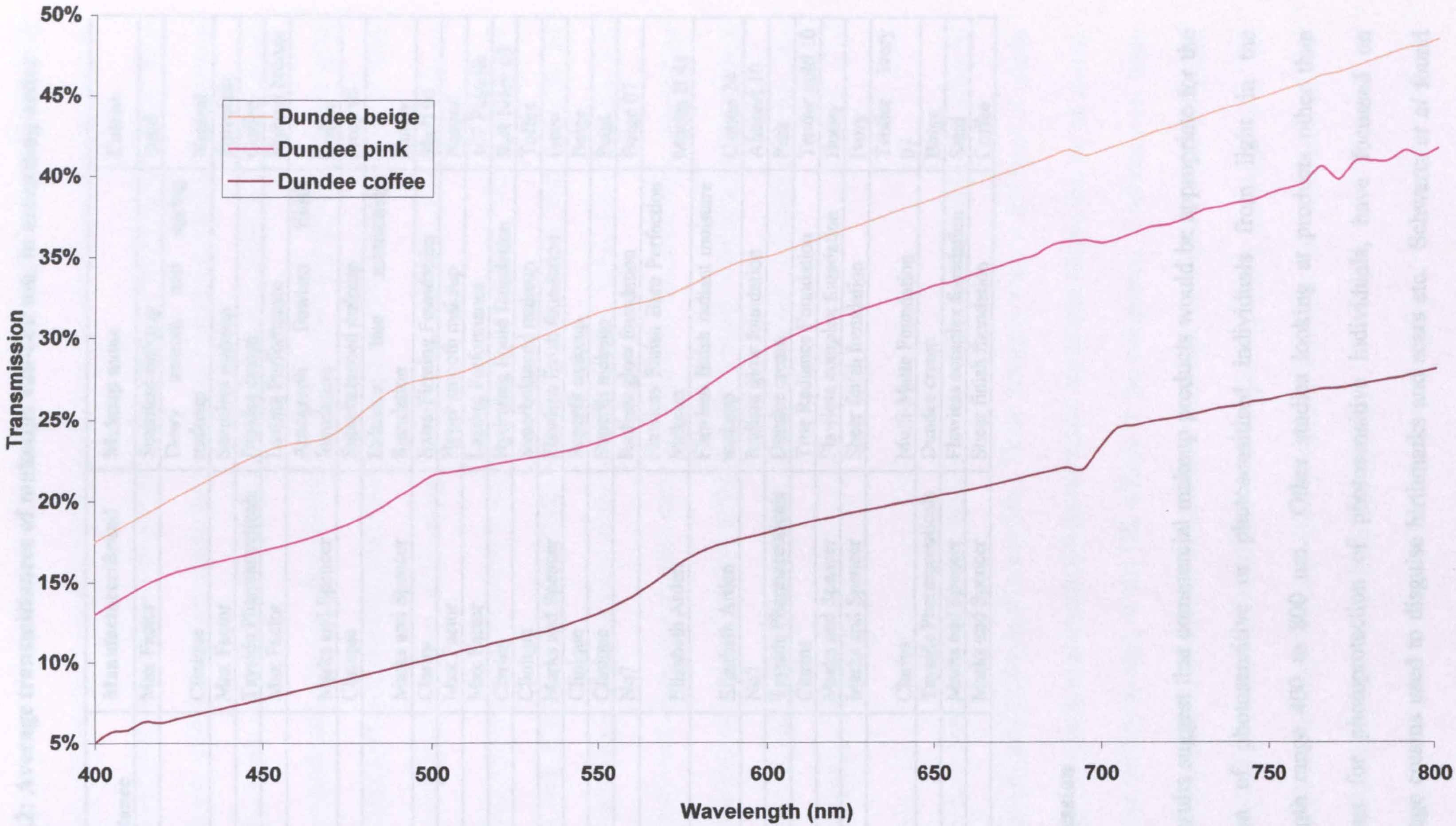

Table 4.2: Average transmittances of makeups 400-800 nm, in ascending order

Average Transmittance	Manufacturer/Brand	Makeup name	Colour
13%	Max Factor	Seamless makeup	Sand
16%	Clinique	Dewy smooth anti ageing makeup	Neutral
17%	Max Factor	Seamless makeup	Porcelain
17%	Tayside Pharmaceuticals	Dundee cream	Coffee
18%	Max Factor	Lasting Performance	Natural bronze
18%	Marks and Spencer	Autograph flawless finish foundation	Coffee
18%	Clinique	Superbalanced makeup	Ivory 03
18%	Marks and Spencer	Enhance line minimising foundation	Honey
19%	Clarins	Extra-Firming Foundation	Shell 05
19%	Max Factor	Hyper smooth makeup	Natural
20%	Max Factor	Lasting Performance	102 Pastelle
22%	Clarins	Hydrating liquid foundation	Soft Ivory 03
23%	Clinique	Superbalanced makeup	Toffee
24%	Marks and Spencer	Flawless finish foundation	Ivory
25%	Clinique	Superfit makeup	Beige
25%	Clinique	Superfit makeup	Petal
25%	No7	Radiant glow foundation	Beige 07
26%	Elizabeth Arden	Flawless Finish Bare Perfection Makeup	Mocha II 41
28%	Elizabeth Arden	Flawless finish radiant moisture makeup	Cameo 24
28%	No7	Radiant glow foundation	Almond 10
28%	Tayside Pharmaceuticals	Dundee cream	Pink
32%	Clarins	True Radiance Foundation	Tender gold 10
32%	Marks and Spencer	Flawless complex foundation	Honey
32%	Marks and Spencer	Sheer finish foundation	Ivory
33%	Clarins	Multi-Matte Foundation	Tender ivory 07
34%	Tayside Pharmaceuticals	Dundee cream	Beige
35%	Marks and Spencer	Flawless complex foundation	Sand
35%	Marks and Spencer	Sheer finish foundation	Coffee

5. Discussion

These results suggest that commercial makeup products would be appropriate for the protection of photosensitive or photosensitised individuals from light in the wavelength range 400 to 800 nm. Other studies looking at products other than sunscreens for photoprotection of photosensitive individuals, have focussed on camouflage creams used to disguise birthmarks and scars etc. Schwartz *et al* found

that *in vivo* testing of dark cover creams showed that they were 3.4 times better than sunscreens and therefore suitable for photosensitive skin [72]. Kaye *et al* assessed *in vitro* and *in vivo* (using an animal model) sunscreens as well as 'Covermark' from 350-800 nm and found that products containing absorbing pigment outperform sunscreens in the visible range [18]. In another similar study in 1982, Hawk *et al* found that Covermark and reflectant titanium dioxide creams provided good protection up to 600nm. However they criticised such products suggesting they were 'unpopular' with patients and indicated that men would not tolerate wearing makeup [1]. Such camouflage creams are complicated to apply, as they have to be set with a powder and removed with special cleansers. Many women use commercial makeups and the range of products available increases their aesthetic appeal. When given a choice, it is highly likely that these commercial makeups would be favoured over camouflage creams and may also be marketed as suitable for both sexes. Furthermore, the amount of protection offered is significant and may have implications for the photodermatology industry.

Attempts were made to contact the manufacturers of the products tested in order to invite them to participate in the research. These attempts were in the form of phone calls to try and speak to research and development teams and failing this (in all cases), letters were written to each of the UK offices of the companies. Unfortunately there was no response from any of the companies. Although the market would be small, some of these products could be marketed to photosensitive patients. It is not suggested, however, that makeup should replace sunscreen for protection of UV sensitive and normal individuals from summer sun.

As a method of topical photoprotection, sunscreens are problematic. It has been shown that people use too little sunscreen to provide the protection suggested by an SPF [9,73] and do not apply products thickly enough [74]. Commonly people apply only ¼ to ⅓ rd of the amount of product used in SPF testing, which results in only ⅓ rd of the stated SPF being afforded, hence the 'rule of nines' as used to assess burn injuries has been suggested as a dosing method for sunscreens [75] but this has not been accepted or publicised by the sunscreen industry.

Sunscreens have also been shown to be potential photosenisisers but furthermore, concerns have been raised regarding the absorption of sunscreen constituents into the body. The safety of any new sunscreen is important and penetration should be low to negligible [76]. However, conflicting work showed that substantial amounts of oxybenzone are absorbed into systemic circulation whilst little is known of its chronic toxicity [44]. Benzophenone-3 also passes through the skin in significant amounts [77]. In individuals that are photosensitive, and while the causes of conditions such as CAD, PLE and SU are unknown (see chapter 3), exposure to potentially photolabile chemicals should be avoided. Physical barriers are therefore a much safer method of protecting sensitive individuals, as has already been suggested by Wolf and Oumeish [36], and also provide a barrier to reduce exposure to allergens [5].

This work could be criticised due to the choice of substrate for testing. Given the close agreement between Vitro Skin tests and *in vivo* SPF's [35], Vitro Skin would have been the preferred substrate for this work. However, the method used to test transmittance, using the spectroradiometer, meant that the exposure time was considerably longer than the short, pulsed exposure that vitro skin was designed for

(using commercial transmittance analyser) and the Vitro Skin desiccated when exposed to the duration and intensity of radiation that the xenon arc lamp provided. Therefore we could not use Vitro Skin and chose Transpore as a next best option and also to keep the testing across the spectrum and range consistent.

Further investigation of the effect of these makeups *in vivo* is indicated. Testing could be carried out on photosensitive volunteers. This kind of study would be a huge undertaking and could be facilitated by investment from interested cosmetic companies.

6. Conclusions

This is the first work that has analysed the protective efficacy of cosmetic products for the protection of photosensitive or photosensitised individuals. The results demonstrate that some commercial products offer substantial protection against light in the wavelength range 400 to 800 nm and rival the Dundee creams which, to date, have been the only products recommended for photosensitive individuals. Colour is not a good indicator of the protection offered and only products that have been tested in work such as this should be recommended.

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Chapter 5

Measurement of cosmetic tanning sources and evaluation of hazards and existing regulations

Spectral irradiance of sunbeds, associated hazards and assessment against existing legislation

Summary

During a one-year period from April 2004 to April 2005 all the premises that offer sunbeds in Dundee and Perthshire were visited. Spectral measurements were made of all the sunbeds and the lengths of sessions available were noted. The results reveal that many sunbeds are stronger than previous studies have suggested, and can have a carcinogenic potential of up to 2.7 times that of southern European sun. Accounting for all the lengths of sessions, the maximum recommended dose for one year (15 kJm^{-2} erythemally effective radiation) could be exceeded in less than 20 sessions on some sunbeds. Most of the units surveyed do not fit into any criteria as given in the British Standard (BS EN 60335-2-27: 1997, Safety of Household and similar electrical appliances, Part 2. Particular requirements, Section 2.27 Skin exposure to ultraviolet and infrared radiation). A Health and Safety questionnaire was also completed and revealed that there are many shortcomings in the way that tanning salons are operated. Questionnaires left for users to fill and return anonymously also indicated that many people are not well informed as to the risks of using sunbeds.

1. Introduction

Throughout the 20th century there has been a fashion for tanned skin. This is a considerable change from the penchant for a 'pale and interesting' appearance, which was vogue in the 19th century. The industrial revolution, the discovery of the therapeutic effects of light, the move of the working classes into indoor jobs, and the suntans which provided evidence of foreign travel have all contributed to the change in trend of preferred skin colour[1]. An excellent review of the history of the suntan is contained in a paper by Randle, written in 1997, including the famous comment by Coco Chanel: 'the 1929 girl must be tanned' [2].

Hand in hand with this fashion has been the increased incidence of skin cancer noticed by epidemiologists since the 1970's. Specifically, melanoma incidences have increased 3-7% in fair skinned populations in recent decades, with a mortality rate of 20% [3]. Rates of non-melanoma skin cancer are also on the increase [4]. Fears over a skin cancer epidemic are further compounded by reports on the thinning of the ozone layer and the potential for increased solar radiation fluences [5-8]. The current cost of care of patients with skin cancer in the UK is estimated at £34 million per year [9].

High profile sun awareness campaigns, such as the Australian 'slip, slop, slap' campaign, launched in the last 25 years, have attempted to change attitudes towards UV exposure [2,10]. In the southern hemisphere, changes in attitudes have been reported [11,12] but for many people the suntan is still desirable [13] as it represents a positive stereotype [14]. Furthermore, increased knowledge of risks does not necessarily correspond to a change in behaviour [12,13,15]. In the UK the picture is similar. Health

promotion campaigns have increased awareness, but the proportion of people developing sunburn has not reduced [16].

It is not surprising that along with a desire for tanned skin would go ways to achieve a tan. Hence the ubiquitous presence of the sunbed*- a way to get and keep a tan even in winter at northerly latitudes. The use of artificial tanning devices has been increasing since the 1960's, [17] when broad spectrum lamps were used to irradiate skin for short periods of time. The last twenty years has seen the advent of the fluorescent UVA lamp, the rise and rise of the tanning salon [18] and the development of high intensity lamps to make sunbed use more viable for the busy professional.

Exposure to UVA radiation used in cosmetic sunbeds to tan the skin is, however, not without its inherent dangers. The acute risks are erythema and photokeratitis if suitable goggles are not worn. There are also reports of phototoxic skin reactions initiated by the use of UVA sunbeds [19]. Ingestion of a large amount of celery led to severe phototoxic burn and hospitalisation in one woman [20] and three tanners choosing to use psoralen to speed up the tanning process were reported to have developed extensive skin burns [21]. Pseudoporphyria is another phenomenon caused by sunbed use [22], where patients develop PCT like symptoms but have normal red blood cell, urine and stool porphyrin levels [23]. While phototoxic reactions are rare, operators and users of tanning beds should be aware of the potential for such reactions and guard against them. Of particular importance is the potential of many prescribed drugs to be photoactive [19].

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* Please note that unless stated, 'sunbed' refers generically to both lie down and stand and tan booths.

Chronic effects of sunbed use are premature skin ageing, increased skin fragility [19], cataract and skin cancer [4]. For many years there has been confusion surrounding the issue of whether or not exposure to UVA radiation causes the potentially fatal form of skin cancer, malignant melanoma.

In the 1980's and 90's there were studies published in reputable journals that cited sunbed use as a risk factor for melanoma. Swerdlow *et al* reported a significantly increased risk (2.9) of melanoma in Scottish sunbed users [24]. One Canadian [25] and one Swedish [26] study also found sunbed use to be a risk factor for melanoma although they quote lower risk factors than the Scottish study.

Conversely, studies were also published citing no meaningful association between melanoma risk and exposure to sunbeds [27,28]. There are several reasons for the confusion evident in the literature.

Poor experimental design is one reason. In 1998, De Guire and Rhiands [17] analysed the findings of fifteen case-controlled studies of malignant melanoma during the period 1979 to 1996. They found only four of these studies to be methodologically sound. Any occurrence of melanoma is always confounded by sun exposure [4], thus any epidemiological evaluation of melanoma occurrence due to sunbed use must be rigorous.

Of those studies that are credible there are further issues to consider. Most importantly is the long latent period for the development of melanoma [29*], so that

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* Study published in 2004 but conducted between 1991 and 1999

subjects may go on to develop melanoma in the future. Hence there have been inconclusive studies published [30]. Many melanoma patients do not admit to having used sunbeds when giving their medical history [31], so complicating the picture. Also, users of older devices may have used devices that emitted UVC radiation [32] and thus their melanoma may not be attributable to exposure to UVA radiation. Thus the qualified medical opinion has been that it is reasonable to assume that exposure to high doses of UVA radiation are dangerous but this was not a firmly established fact at the end of the millennium [33].

More recent publications are less equivocal regarding the potential for UVA to cause skin cancer. Bataille *et al* [34] assess the risk of melanoma for fair skinned individuals in the UK using sunbeds as increased by a factor of 2.66 but state that due to the lag time between exposure and development of melanoma, they may have underestimated the risk. Diffey [35] estimates that 100 melanoma deaths in the UK each year are attributable to sunbed use.

There is a widely held belief, perpetuated by the tanning industry, that tanning on a sunbed is safer than tanning in the sun [19,29,36,37]. In fact, it has been found that sunbeds produce similar levels of radiation to that produced by the midday Mediterranean sun so that sunbeds are in fact no safer than the sun but can increase yearly doses dramatically if used regularly [38]. Furthermore, there is biological evidence to support the hypothesis [39] of the carcinogenic potential of UVA radiation [40-46].

Within the context of environmental technology, this chapter would not be complete without a sociological consideration of why people feel compelled to use sunbeds despite warnings from the medical profession that their use is inadvisable for cosmetic tanning [47,48]. A review of the psychological literature reveals that the main motivations are to look and feel better [15]. Boldeman *et al* report that the sunbed use is twice as common in young females as males [49] and young, professional women are thought to be the most likely to use sunbeds [50,51].

Although motivations for using sunbeds are complex and multiple, commonly cited reasons for the use of sunbeds are to promote feelings of well-being and attractiveness and can be correlated with physical activity in many cases, possibly due to the placement of many sunbeds in gymnasiums [36]. In a survey of adolescents, it was found that boys achieving the highest scores for self worth are most likely to use sunbeds and girls with the lowest scores for self worth are also most likely to use sunbeds [52,53]. Adolescents are also more likely to use sunbeds if their friends or parents do and access is rarely regulated [54]. Use among school children in Scotland has also been reported; a Lanarkshire survey of 1405 children aged 8-11 revealed that 7% had used sunbed [55]. This worrying finding suggests that parents believe UVR to be beneficial.

There is also a reported link between sunbed use and smoking behaviour [36,56,57] possibly due to a similar cognitive dissonance between UVR effects and tanning as there is between smoking and lung cancer [58,59]. There is a reported 'unrealistic optimism' among sunbed users [13] and one American study found that 10% of users would still choose to use sunbeds even if they were proven to cause skin cancer [50].

The consequence of the high level of demand for sunbed use is an increase in the possibility of negative physiological effects from exposure to UVA radiation. This idea was backed up by a study in which frequent sunbed users were offered a blind choice between identical sunbeds, one of which had only visible light tubes in and the other that was UVA. 95% of the elected exposures were on the UVA bed therefore suggesting that there is some reinforcing stimulus from UV exposure [60]. Some research groups have investigated the presence of beta-endorphins after UV exposure as a possible mechanism for the sense of well being reported after sunbed use. This particular mechanism has been rejected [61,62]. Further work to elucidate the mechanism of the positive psychological benefit would be useful in developing our understanding of the popularity of the use of sunbeds and the 'addiction' that some users seem to develop [22]. Armed with this knowledge the medical profession could then suggest alternative and less risky ways of creating this benefit.

Legislation

Given the potential risks of sunbed use it would be reasonable to assume that the use of these units was legislated. However, there is no specific legislation covering the provision of artificial tanning units. Premises offering sunbeds fall under the legislative capability of the Health and Safety at Work etc Act 1974 [63]. The Health and Safety Executive has produced a set of guidelines for users and operators of sunbeds [64].

Within these guidelines operators are told that, according to the relevant legislation, they need to:

- assess the health and safety risks caused by work activity; including
    - risks to employees and customers from exposure to UV radiation; and
    - take measures to reduce these risks as far as reasonable practicable.

Hence, a risk assessment for employee exposure to radiation from sunbeds is required under the Health and Safety at Work etc Act 1974.

The rest of the HSE document is only guidance. It suggests that operators should

- Be able to say what the nature and extent of UV hazards are
- Know the health risks associated with use of UV tanning equipment
- Know the extent to which exposure to UV can vary according to the lamps that are in the equipment
- Have information from supplier on extent and magnitude of the UV hazard
- Advise customers on duration of and periods between each session
- Limit total sessions per year (recommend 20)
- Screen beds to prevent accidental exposure
- Record the date and length of each customer's session

Sunbed operators may choose to ignore the HSE guidelines but following them certainly ensures compliance with the law [64].

Survey of premises offering cosmetic tanning in East Scotland

During the period from April 2004 to April 2005, 50 premises that offer sunbeds for cosmetic tanning in the local authority areas of Dundee City Council and Perth and Kinross Council were visited.

In Dundee, council health and safety officers compiled a list of those premises with sunbeds from local knowledge and records. There were 24 premises in total, 3 of which are operated by the local authority. Authorisation was given to enter the premises with an inspector under section 20(2)(C)(i) of the Health and Safety at Work Act, 1974. Hence, these visits were accompanied by one of the environmental health officers from Dundee City Council. All but one of the commercial premises were successfully visited, this final one being closed on each occasion a visit was made. At the same time as the measurements were made, the officers inspected each business to check that Health and Safety guidelines were being followed.

In Perthshire, all local authority facilities have removed their sunbeds so only commercial premises were visited. In the first place an environmental health officer wrote to the 11 businesses that were known to offer sunbeds. The letter alerted the owners to the survey and informed them that they would be visited and also offered to discuss any worries prior to the visit. A further 10 premises were identified because they formed part of the survey undertaken by Moseley *et al* in 1997 [65]. A further 7 businesses offering sunbed use were identified by telephoning all the hairdressers, beauty salons, sports centres and gyms listed in the Yellow Pages. One tanning parlour of which the council were aware, had closed down between the letter being

written and the proposed visit. Hence a total of 27 businesses were contacted and visited; all co-operated fully by making the units available, switching them on and answering questions asked.

Aims of the survey

- Find out exactly how many sunbeds were available and in what type of premises.
- Undertake on site spectral measurements at all premises to determine strength of radiation from beds.
- Determine whether sunbeds used commercially operate within parameters in existing British Standard (BS EN 60335-2-27: 1997, Safety of Household and similar electrical appliances, Part 2. Particular requirements, Section 2.27 Skin exposure to ultraviolet and infrared radiation) classifications, hereafter referred to as BS.
- Find out whether the premises were compliant with the relevant legislation.
- Compare the results from with the similar survey (of Perthshire) undertaken in 1997.
- Determine the number of sessions in each premises, on each bed, that would be within recommended safe limits for one year.
- Estimate carcinogenic risk from the sunbeds.

2. Methods and Materials

Instrument and calibration

On site measurements were made using a Sola-Scope handheld UV spectroradiometer, Type SC-MP-A, from 4D Controls (Redruth, UK). This model of instrument was evaluated for measurements of phototherapy units (see chapter 2), however, the instrument purchased and used for this survey had a response that did not match the instrument evaluated (the purchased instrument was less sensitive), hence the calibration method with the 1 kW FEL lamp could not be used. Instead, the instrument was calibrated at the Photobiology's United Kingdom Accreditation Society's (UKAS) accredited laboratory, using a recognised protocol. This method employs fluorescent UVA tubes with a similar spectral distribution to those that are found in cosmetic sunbeds. Simultaneous measurements were made at 20 cm from the UVA tubes with the Sola Scope and a bench based double grating spectroradiometer (Bentham DM150). The spectroradiometer has a calibration factor derived from measurement of a tungsten halogen lamp calibrated at NPL. A calibration factor at each half nanometre was derived for the Sola Scope thus:

$$CF_{\lambda} = \frac{E_{B\lambda}}{E_{SS\lambda}} \qquad \textbf{ion 5.1}$$

where

CF is the correction factor at wavelength λ

E_B is the irradiance as measured by the Bentham spectroradiometer at wavelength λ

E_{SS} is the irradiance as measured by the Sola Scope at wavelength λ

Hence multiplication of any measurement taken by the Sola Scope by the correction factor gives the irradiance as would have been measured by the Bentham.

A second calibration was made in a similar fashion using a metal halide source for use with those sunbeds that have metal halide lamps either as their main tanning source or as facial lamps. This is also a UKAS accredited measurement.

The calibration of the Bentham is traceable to the National Physical Laboratory (Teddington, UK) and has an expanded uncertainty at the 95% confidence level, of 5.89 % in UVA. The transfer standard for UVA radiation measurements is a 100W, frosted glass, tungsten lamp. Thus an estimated uncertainty of +/- 15% can be attributed to the Sola Scope measurements. This is in agreement with similar studies of similar measurements [66].

Figure 5.1: Sola Scope SC-MP-A

Measurement of sunbeds

All sunbeds were allowed 3 minutes to warm up prior to commencing measurements.

Lie down units

Lie down units are those traditionally thought of as 'sunbeds' where the user lies flat on the bottom of the bed and lowers a canopy down over the their body (see figure 5.2). There were also beds that feature irradiation just from above the user, so that they have to turn over half way through their session. In each case measurements were made using the positions shown in figure 5.3. These positions represent the theoretical maximum spread of a person on the bed. For the base of the bed (where the customer lies) the Sola Scope was placed in a stand (built by request by Medical Physics research and development), pointing downwards (see figure 5.4). This was designed to exclude reflected light originating from the canopy. Spectra were then recorded at positions 1-9 across the base of the bed. For measurements of the canopy, the bottom of the bed was covered with black cloth and the meter was placed in its stand at a fixed height of 20 cm from the base of the bed (see figure 5.5). If the bed had separate metal halide facial tanning lamps then spectra were recorded for positions 1-9 and 1F-3F. If there were not separate metal halide facial tanning lamps, then positions 1-9 were adjusted accordingly to gather average readings for the whole bed.

Figure 5.2: A lie down tanning unit

Figure 5.3: Measurement positions

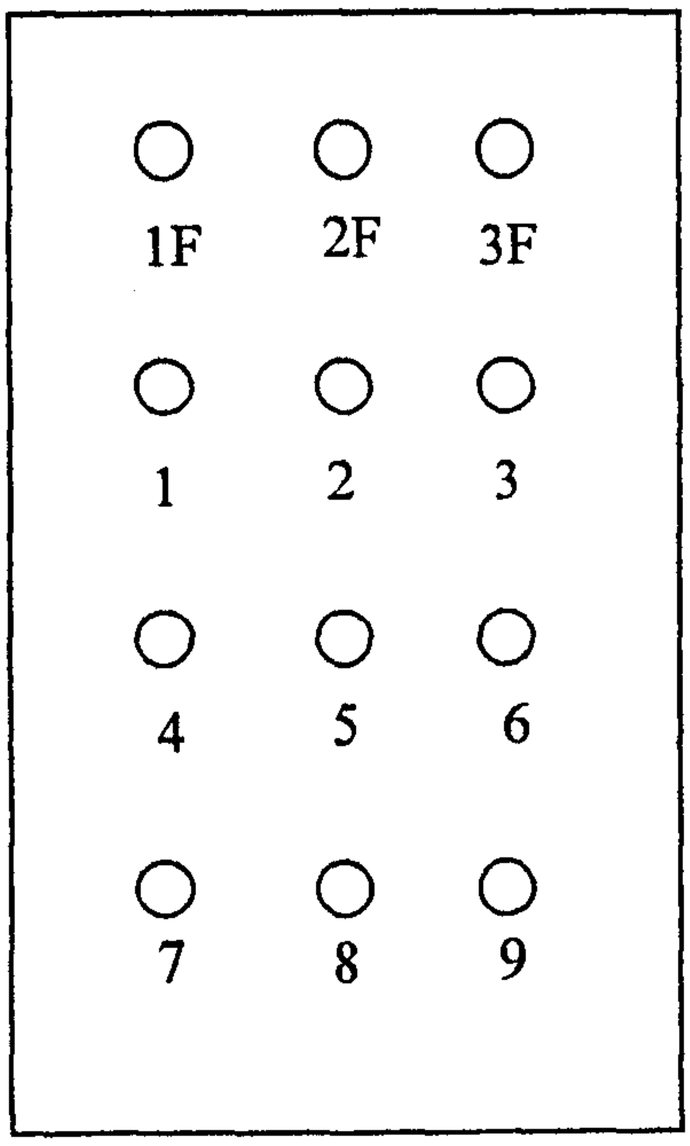


Figure 5.4: Measurement of the bottom of a lie down unit

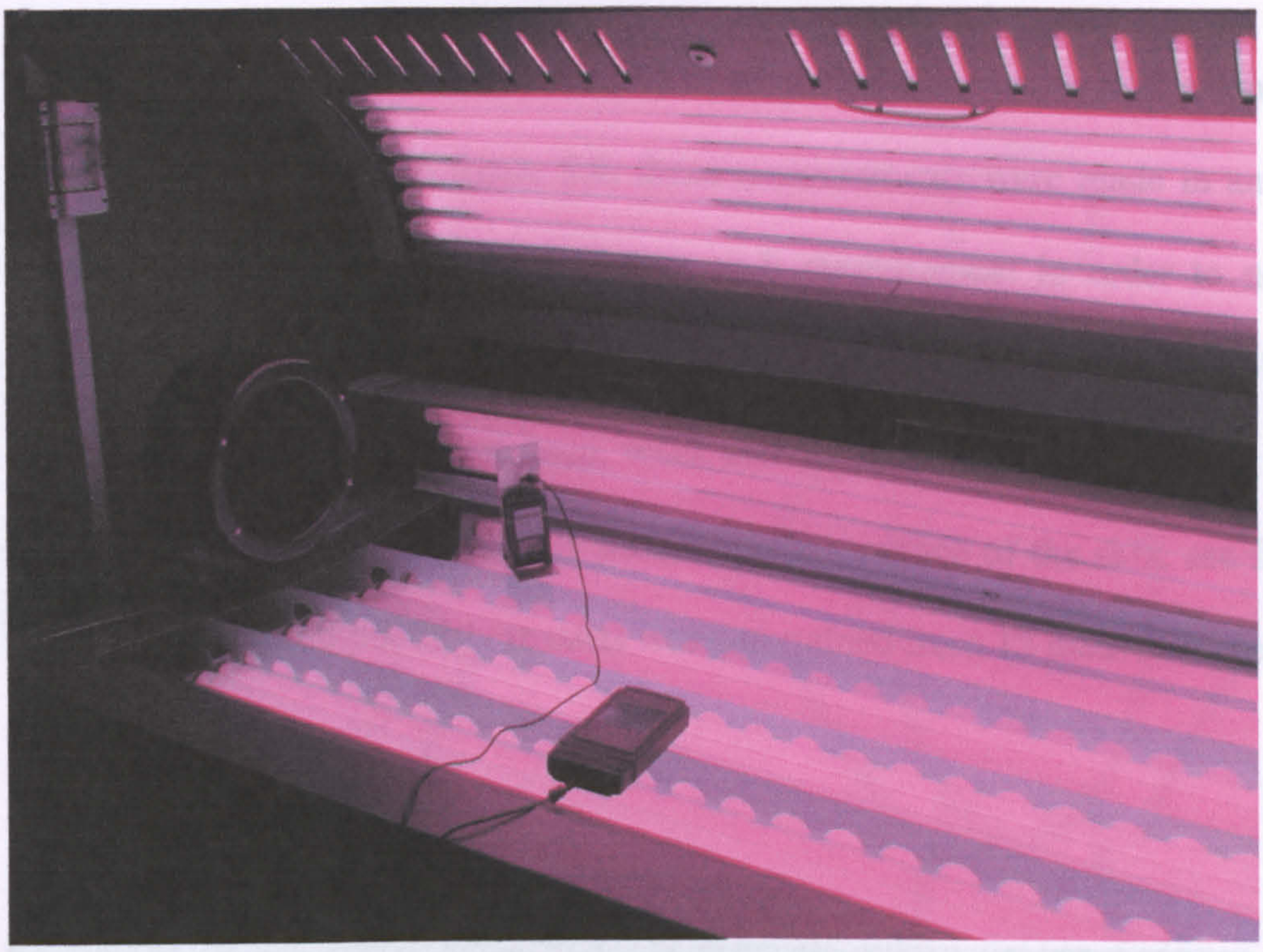


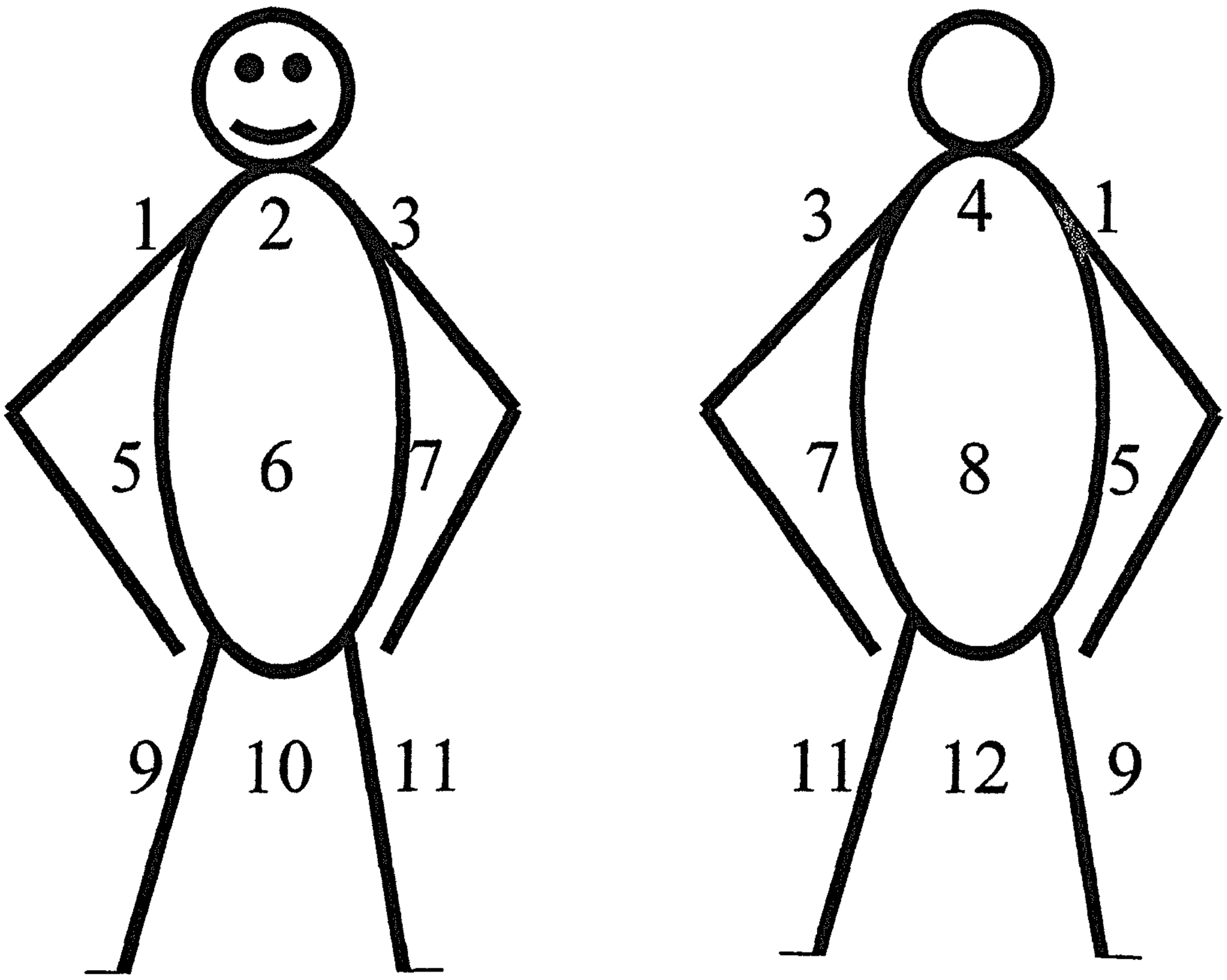
Figure 5.5: Measurement of the top of a lie down unit

Stand up booths

In order to account for the absorbance and reflection of a customer in a stand up unit such as those depicted in figure 5.6, these measurements were made in an occupied booth. A white coat was worn during each measurement in order to negate any effects of different clothes altering the absorbance and reflection of the UV light. Four spectra were recorded at knee, waist and shoulder height, (front, left, right and back) with the detector as flush as possible to the surface of the skin, see figure 5.7. Thus the average output of these units was determined from 12 measurements.

Figure 5.6: Stand up units

Figure 5.7: Measurement positions [67]



Treatment of data

An average irradiance was determined for each bed by taking the mean of the spectral measurements. In order to assess whether or not each of the booths falls within the limits in the BS, the erythemal action spectrum, see figure 5.8 was then applied to the mean spectral data. This weighting function takes account of the relative effectiveness of different wavelengths to induce erythema. The UVB (280-320 nm) and UVA (320-400 nm) effective irradiances were calculated in order to classify the sunbeds (see table 5.1).

Figure 5.8: Erythemal action spectrum [68]

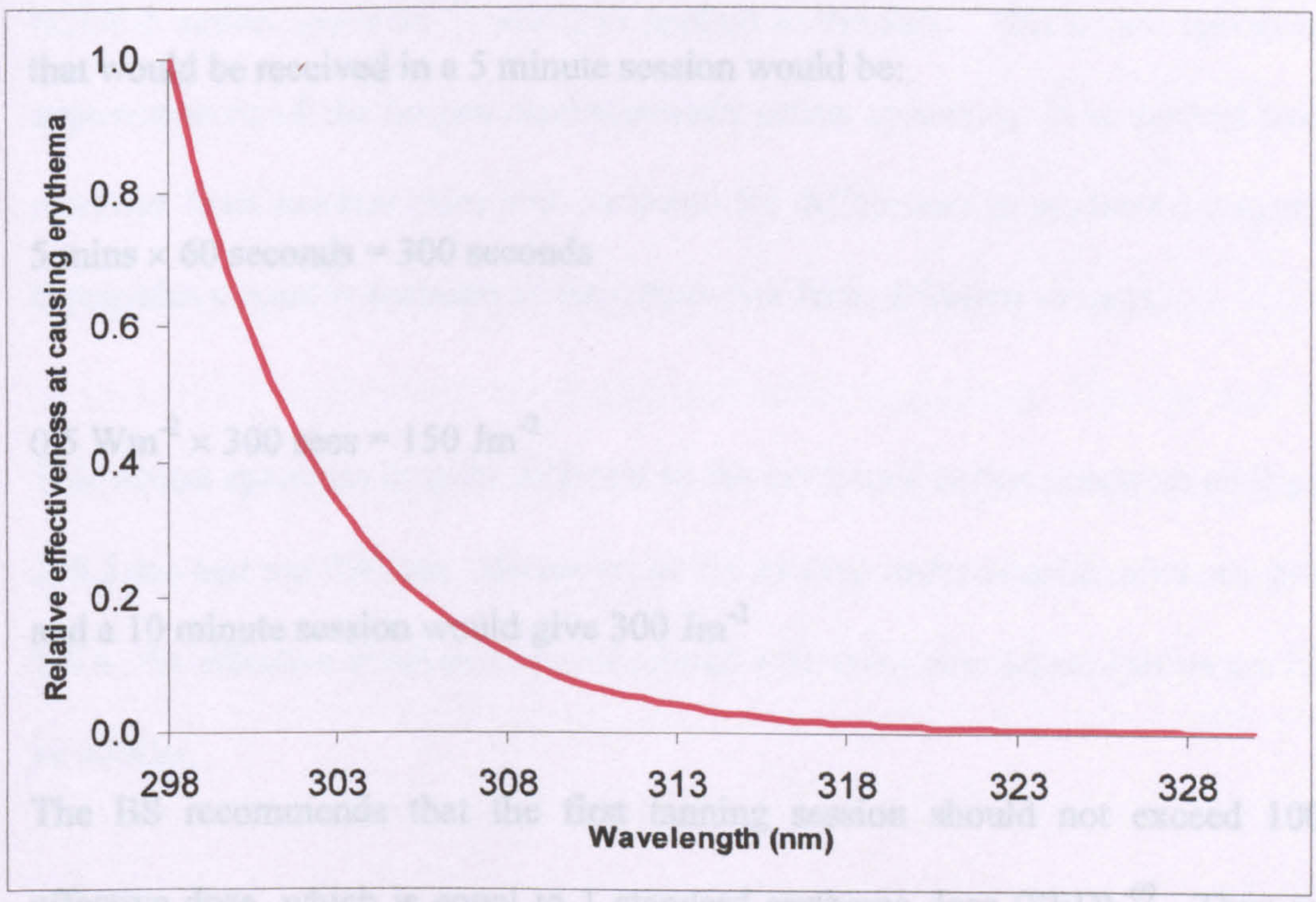


Table 5.1: BS classification of sunbeds, based on erythemal effective irradiance

UV Type appliance	Effective Irradiance (Wm^{-2})		Use
	$250 < \lambda \leq 320$ nm	$320 < \lambda \leq 400$ nm	
1	<0.0005	≥ 0.15	Supervised*
2	0.0005 to 0.15	≥ 0.15	Supervised*
3	< 0.15	< 0.15	Unskilled
4	≥ 0.15	< 0.15	Following medical advice

Effective irradiances were also used to calculate the dose received during each session offered in each salon visited. For example, if tanning parlour X offered 5 and 10 minute sessions on sunbeds that had a total effective irradiance of 0.5 Wm^{-2}, the dose that would be received in a 5 minute session would be:

5 mins × 60 seconds = 300 seconds

0.5 Wm^{-2} × 300 secs = 150 Jm^{-2}

and a 10 minute session would give 300 Jm^{-2}

The BS recommends that the first tanning session should not exceed 100 Jm^{-2} effective dose, which is equal to 1 standard erythema dose (SED) [69]. Thus salon X

* Supervised by 'appropriately trained persons' in 'tanning salons, beauty parlours and similar premises'.

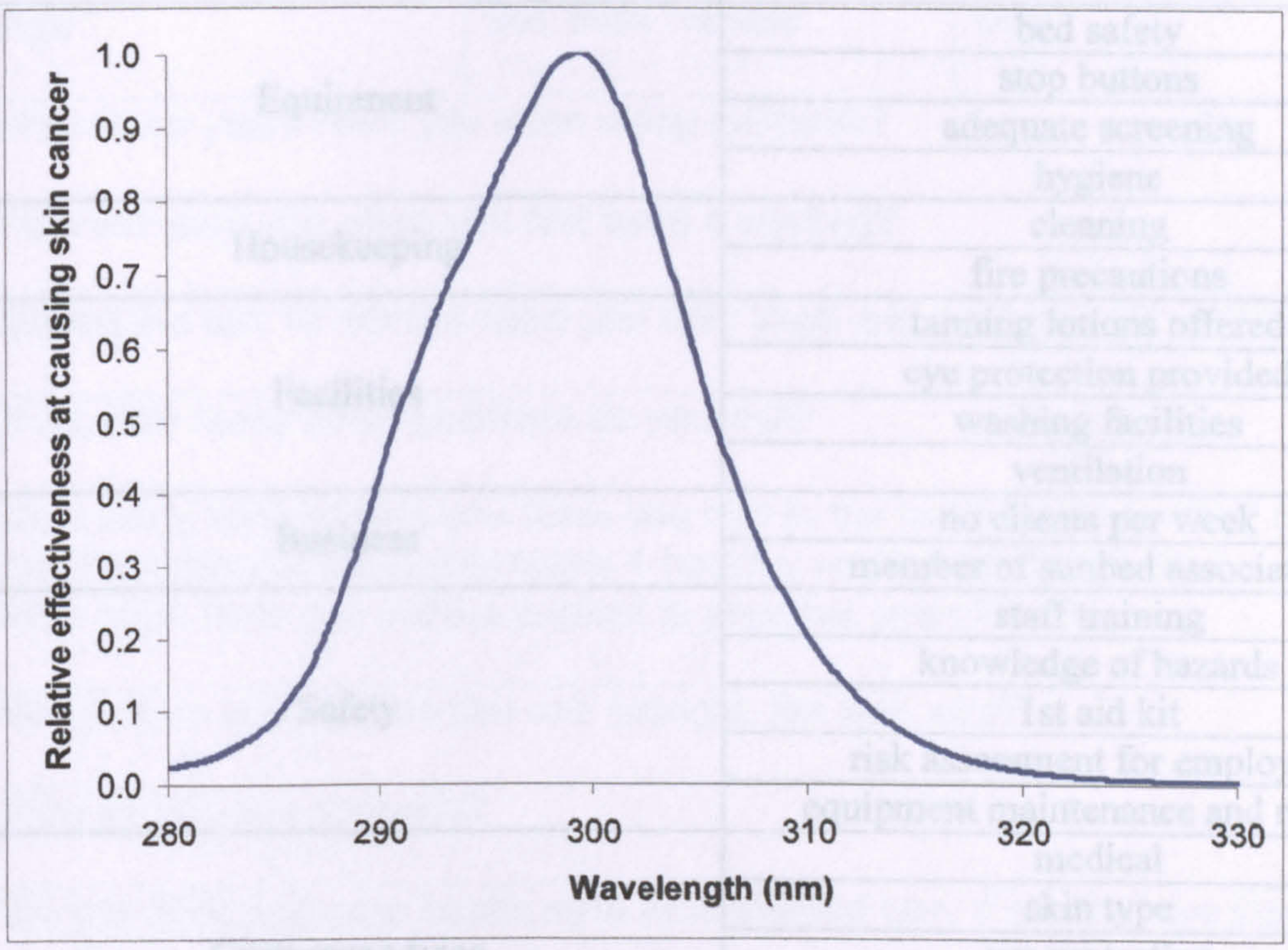
offers 2 sessions, 1.5 SED's and 3 SED's, both greater than the recommended first session time.

The BS also recommends that not more than 15 kJm^{-2} effective dose is received in one year. By calculating each dose during each session and calculating the total number of sessions required to reach this top dose, this can be compared to the British Photodermatology Group recommendation of 20 sessions per year [70], and the sunbed association's 60 sessions per year can be tested. Whether or not blanket advice such as this is sensible, given that the dose received in one 'session' can vary hugely according to the strength of the lamp and the length of the session, will be shown from this data.

In order to compare the results from this survey with a similar one done in 1997, the SCUP-h action spectrum [71] was also applied to the data. This action spectrum is an approximation of the human carcinogenesis action spectrum. It is derived from data recorded from hairless mice and corrected for differences in epidermal transmission. It provides a relative measure of the cancer risk from different sources.

This action spectrum is quite different to the erythemal action spectrum as it peaks at 299.5 nm and not 280 nm. However, as the sources under consideration are primarily UVA, the effective irradiances as calculated with these two action spectra are likely to be similar.

Figure 5.9: SCUP-h action spectrum [71]



Health and Safety assessment of premises

A checklist was drawn up (table 5.2) in order to assess how the businesses operated in terms of their compliance with health and safety legislation. The list also covered how non-legislated aspects such as customer record keeping and enforcement of guidelines on total number of sessions in a year were approached.

Table 5.2: Inspection points

Inspection area	Assessment point
Equipment	bed safety
	stop buttons
	adequate screening
	hygiene
Housekeeping	cleaning
	fire precautions
Facilities	tanning lotions offered
	eye protection provided
	washing facilities
	ventilation
Business	no clients per week
	member of sunbed association
Safety	staff training
	knowledge of hazards
	1st aid kit
	risk assessment for employees
	equipment maintenance and records
Customer advice	medical
	skin type
	eye protection
	display advice
	take away advice
Records and controls	records kept
	length of session
	time between sessions
	total sessions per year
	recording of accidents

User survey

A number of questionnaires were left at each premises together with pre paid envelopes for their return. Table 5.3 shows the questions in the questionnaire.

Table 5.3: User questionnaire

Age :	Sex: male / female	Date:
How many years have you been using sunbeds?		
How old were you when you first used a sunbed?		
During the last 12 months have you only used one premises for sunbeds?		
If no, how many other premises do you visit?		
How many sunbed sessions have you had in the last twelve months? (e.g. 20 half-hour sessions, approximately 4 hours a week every week etc.)		
How often have you used a sunbed in previous years?		
Which type of bed(s) do you use (upright, tan fast, etc)?		
Why do you use sunbeds?		
Do you think there are health risks from sunbed use, if so what are they?		
What information were you given prior to using the sunbed?		
Do you wear goggles when using the sunbed?		

3. Results

Premises types and numbers

There were a total of 50 premises in Dundee and Perthshire, with 133 sunbeds.

The premises were classified according to the main type of business they were involved in (figure 5.10) and then each given an unique identifying number. Many of the gyms were part of a hotel leisure complex, but they have been classified as gyms because most of the sunbed users were people living locally who had become gym members. Hence, those premises classified as holiday resorts were those where the

use of the sunbed was restricted solely to use by holidaymakers and not by regular users. Perthshire and Dundee had similar businesses in each area except there were holiday resorts and beauty salons in Perthshire, and the supermarket with a tanning area located at the back of the shop in Dundee (see figure 5.11).

Figure 5.10: Types and numbers of premises

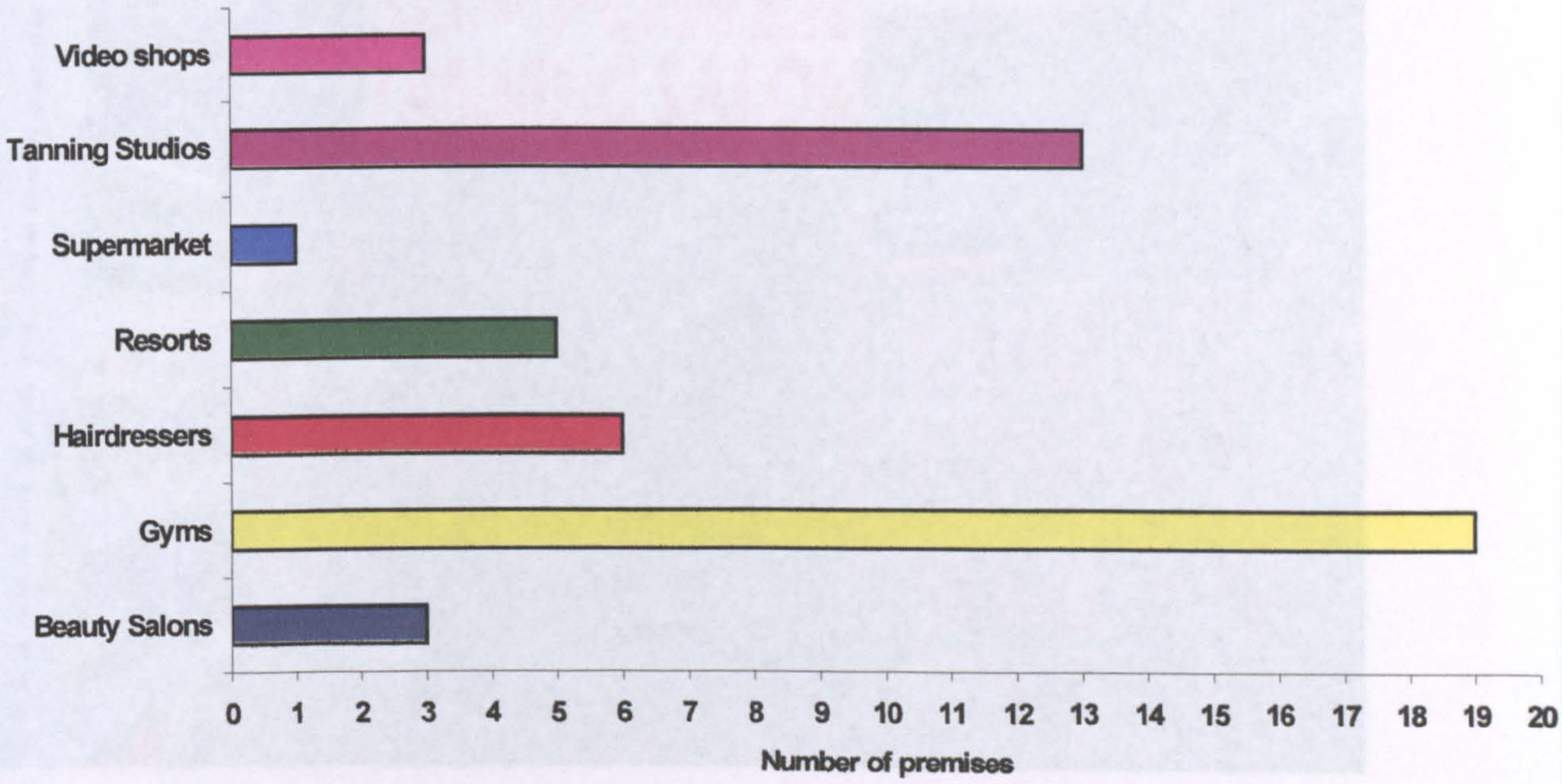


Figure 5.11: Supermarket in Dundee with a sunbed area in the back. The area had not had a ventilation system installed and was partitioned with room dividers that did not reach the ceiling

The numbers of beds in each premises varied from a maximum of 12 in one video shop to the median of 1 unit in 58 % of places (figure 7.12). 73% of the tanning units were lie-down units (beds) and the remaining 27% were stand-up units (booths). Stand up units are generally marketed as being 'fast-tan' units and were found in 1997 to be the strongest units of the two types [65].

Figure 5.12: Numbers of beds in each premises

Perthshire

In Perthshire there were 27 premises, with 47 tanning units (22 beds and 25 booths). This is a decrease in the number of premises, but an increase in the number of sunbeds since the survey was done in 1997 [65] when there were 32 premises and 41 sunbeds. In fact, the rise in the number of sunbeds is due to the opening of two new tanning salons and a video shop in Perth City centre offering multiple units.

There were 16 premises that had not changed numbers or availability of beds since 1997. The 5 local authority leisure centres had removed their units and 6 businesses

had either closed or dispensed with their sunbeds. Hence, 11 premises were visited for the first time, only 4 of which were known to the council and a further 7 that were identified by telephone enquiry.

Dundee

There are 23 premises in Dundee with 86 beds (43 beds and 43 booths). Three of these are local authority sports centres (gyms), one of which has 6 sunbeds and the others which offer just one.

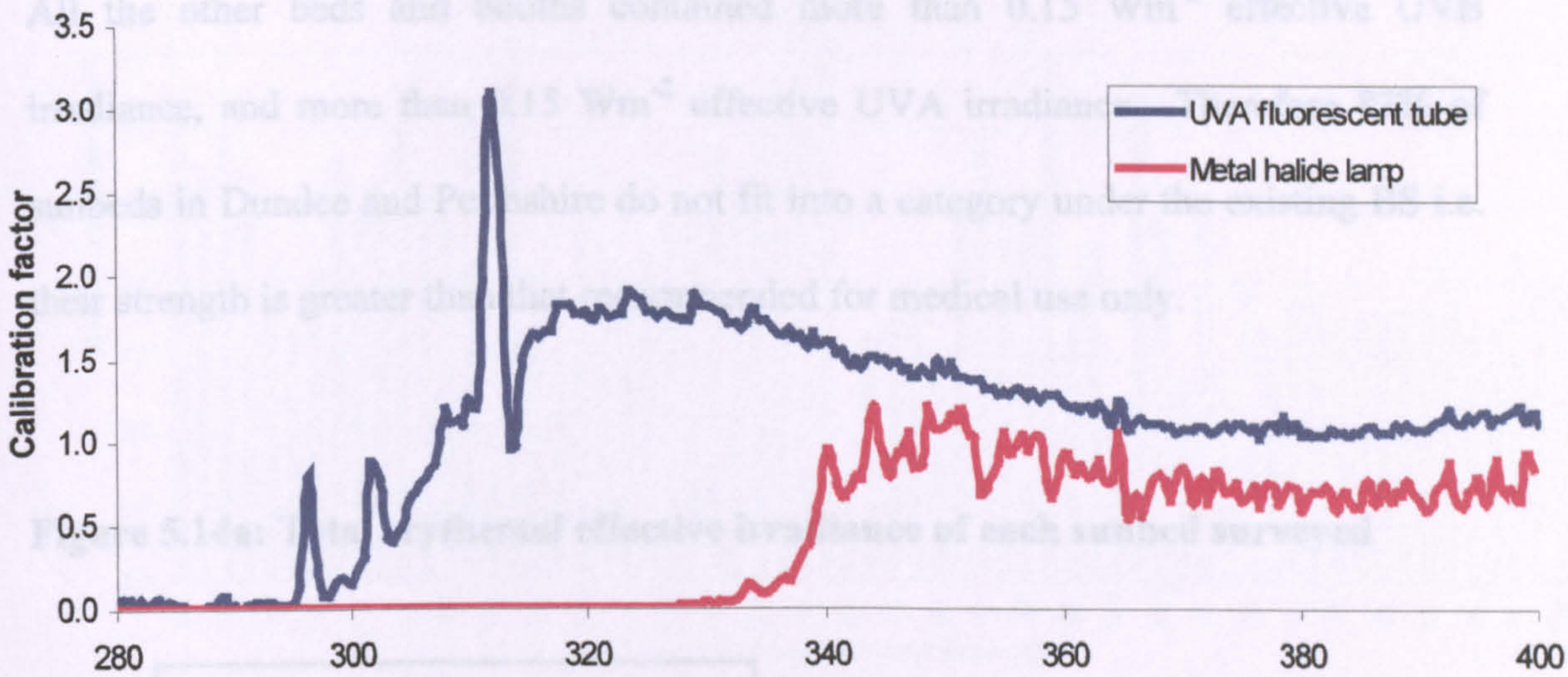
Spectral Measurements

Calibration of the instrument

Separate calibrations were made for fluorescent UVA tubes and for metal halide lamps, see figure 5.13. The mean calibration factor for UVA fluorescent tubes was 1.11, indicating an underestimation of the irradiance from the instrument if its in built calibration were used. In particular, the peak at 312 nm had to be corrected by a factor of 3.

Conversely, with the metal halide lamp, the average correction factor was 0.4 indicating that the Sola Scope overestimated the irradiance from this lamp using its in built calibration factor. The relative differences in these calibration factors are likely to be due to the different spectral distributions of these lamps, creating different stray light profiles, which are then calibrated out.

Figure 5.13: Sola Scope calibration factors



Measurements of the sunbeds

The erythemal effective UVB, UVA and total irradiances from each sunbed were calculated. Total values ranged between 0.02 Wm^{-2} and 0.93 Wm^{-2}, with a mean value of 0.41 Wm^{-2}. Comparing the magnitude of the UVB portion with the UVA portion allows the beds to be classified with the BS system. Figure 5.14a and 5.14b shows the total effective irradiances of each bed. Only 22 (17%) of the units were type 3 and therefore suitable for unskilled use. Two of these were stand up booths, the rest were lie down units including the 8 local authority run beds.

One lie down sunbed was classifiable as a type 3 as the UVB irradiance was below 0.15 Wm^{-2} effective and the UVA was greater than 0.15 Wm^{-2} effective irradiance. This bed, however, was in the unmanned salon and therefore there was no supervision available.

All the other beds and booths contained more than 0.15 Wm^{-2} effective UVB irradiance, and more than 0.15 Wm^{-2} effective UVA irradiance. Therefore 83% of sunbeds in Dundee and Perthshire do not fit into a category under the existing BS i.e. their strength is greater than that recommended for medical use only.

Figure 5.14a: Total erythemal effective irradiance of each sunbed surveyed

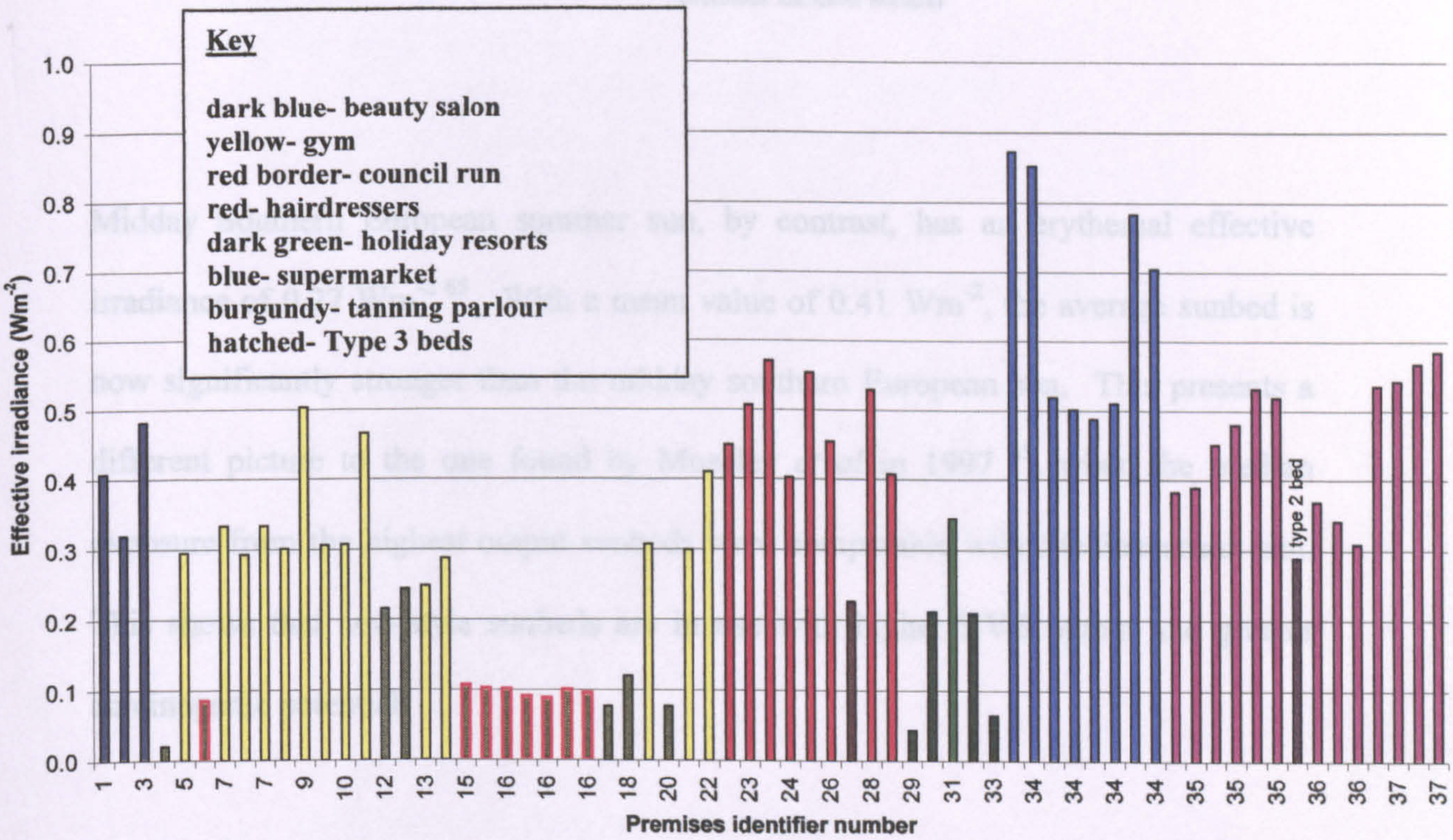
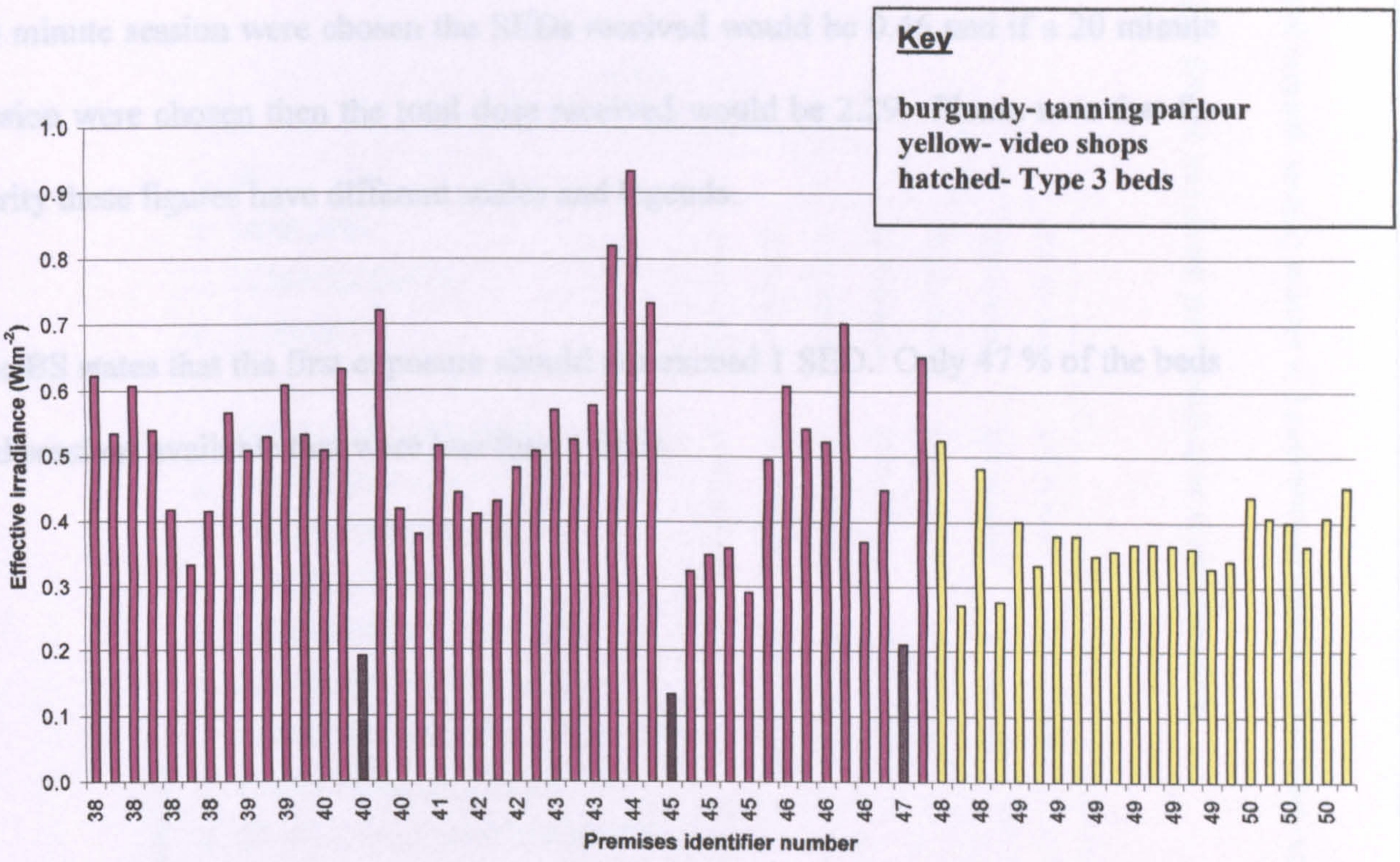


Figure 5.14b: Total erythemal effective irradiance of each sunbed surveyed



Midday Southern European summer sun, by contrast, has an erythemal effective irradiance of 0.27 Wm^{-2} [65]. With a mean value of 0.41 Wm^{-2}, the average sunbed is now significantly stronger than the midday southern European sun. This presents a different picture to the one found by Moseley *et al* in 1997 [65], when the median exposure from the highest output sunbeds were comparable with Mediterranean sun. This shows that new-style sunbeds are in use with higher UVB output and greater carcinogenic potential.

Figures 5.15a to 5.15d show the does in SEDs that would be received during each available session length in each premises, on each sunbed. For example, premises 16 (see figure 5.15a) has 6 beds on which one can have a 20 minute session only. The

numbers of SEDs received during this time are between 1 and 1.27 SEDs. Premises 40 (see figure 5.15a) offers one bed and sessions of 4, 6, 9, 12, 15 and 20 minutes. If a 4 minute session were chosen the SEDs received would be 0.46 and if a 20 minute session were chosen then the total dose received would be 2.29. Please note that for clarity these figures have different scales and legends.

The BS states that the first exposure should not exceed 1 SED. Only 47 % of the beds had sessions available that were less than 1 SED.

Figure 5.15a: Doses received per session at each premises

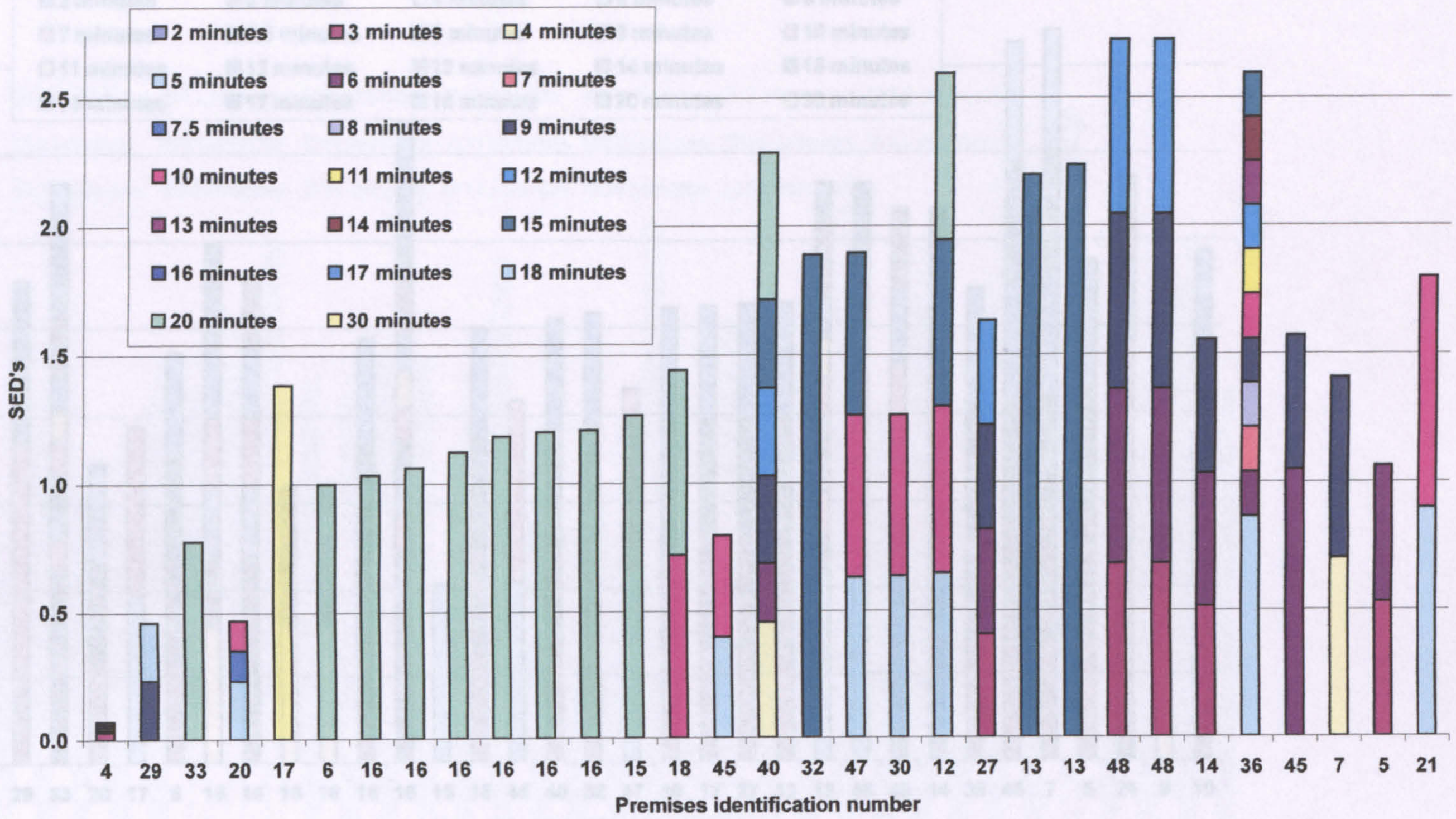


Figure 5.15b: Doses received per session at each premises

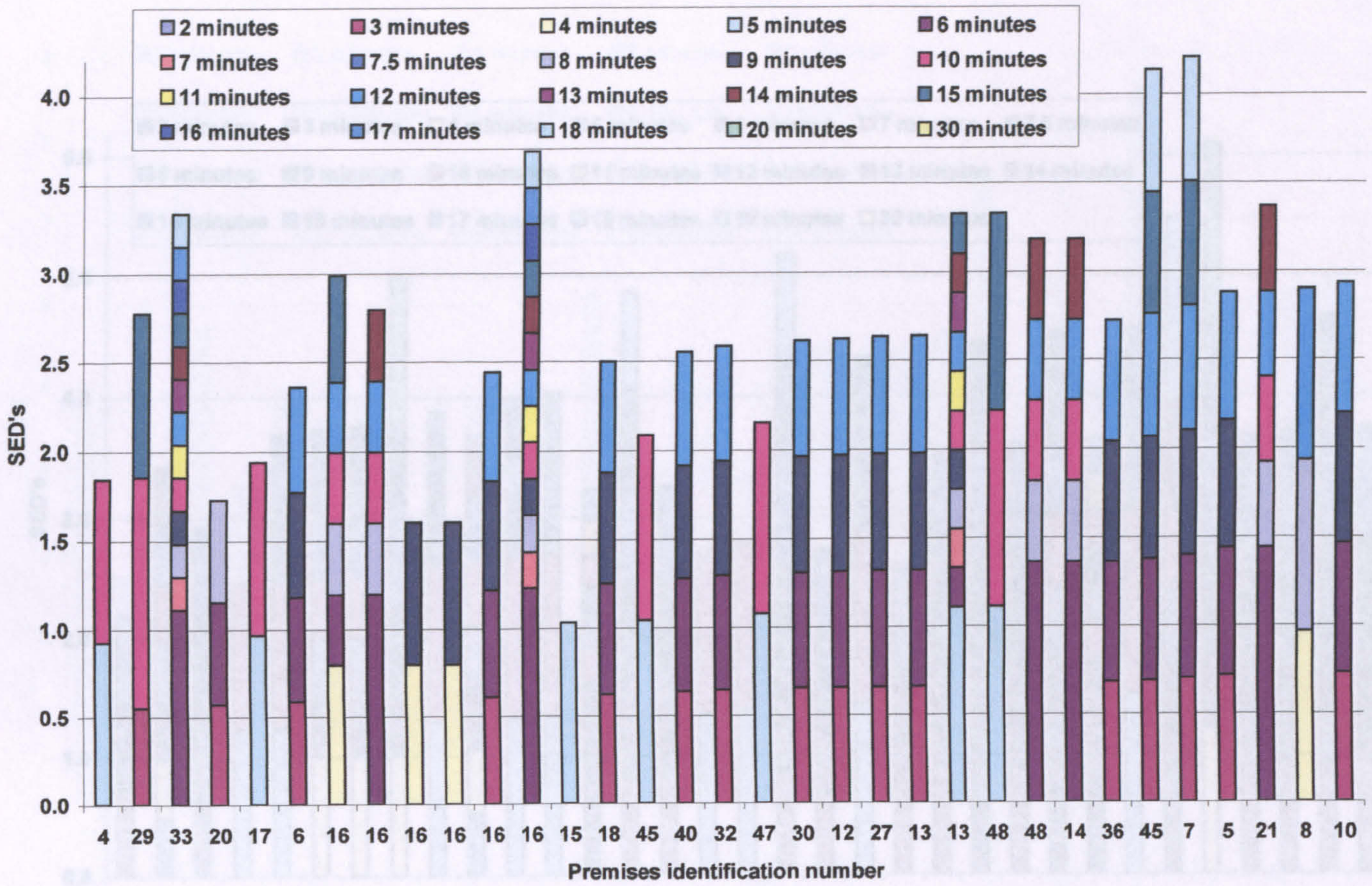


Figure 5.15c: Doses received per session at each premises

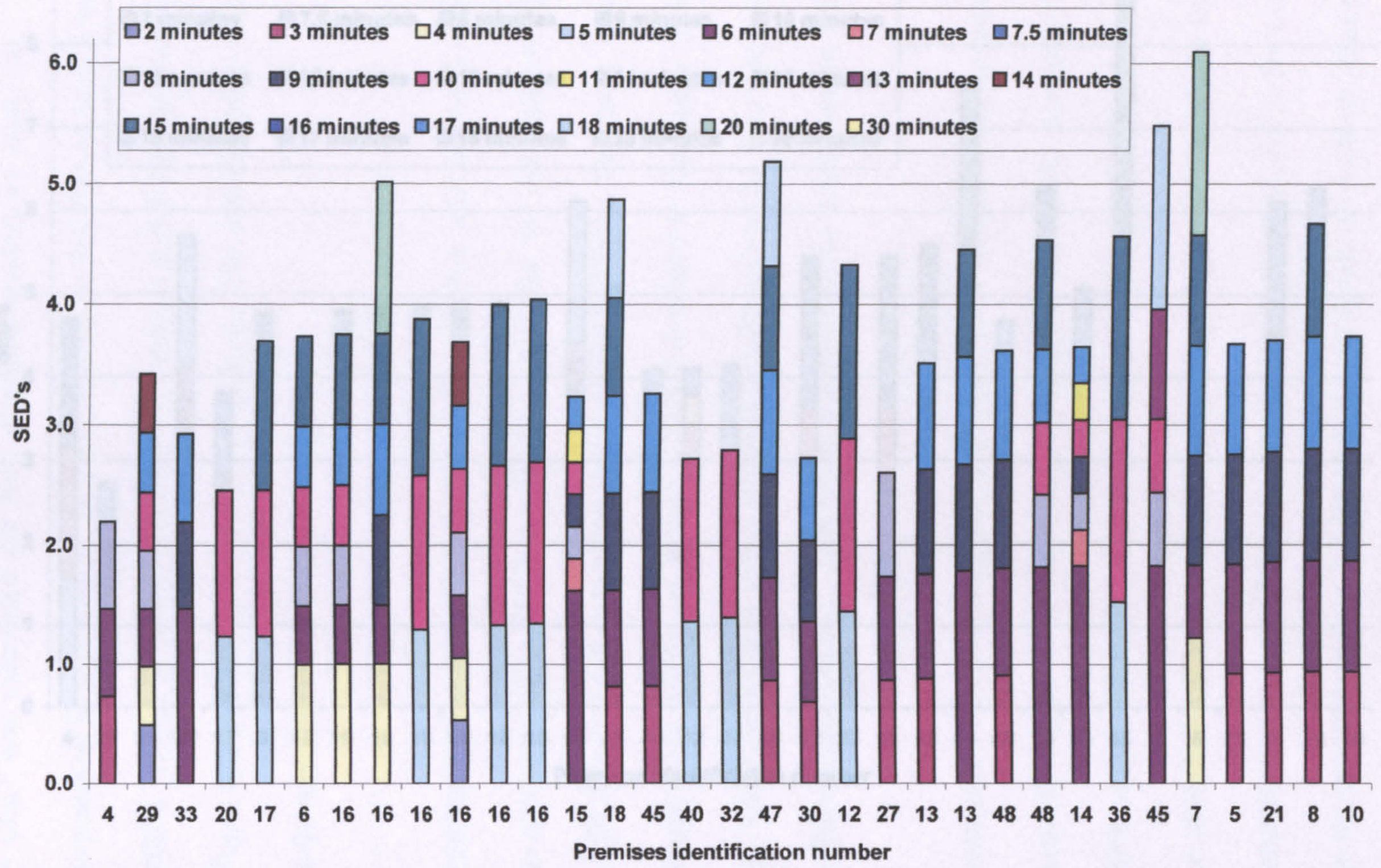
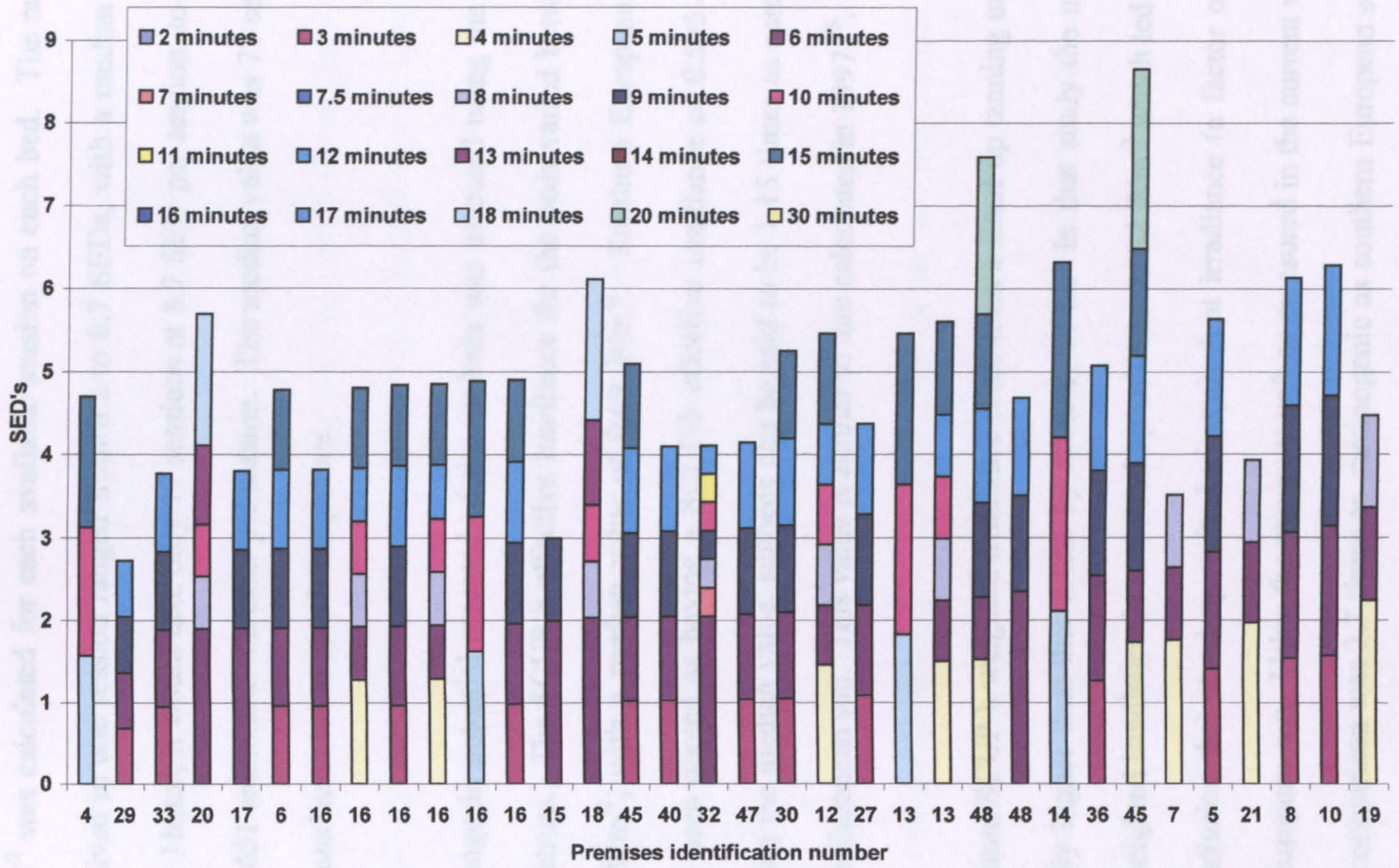


Figure 5.15d: Doses received per session at each premises



The number of sessions that it would take to reach the maximum recommended dose of 15 kJm^{-2} was calculated for each available session on each bed. The number of SEDs received in one session ranged from 0.2 to 8.7 SEDs, with a median value of 2.1 SEDs. Hence, it would take only 17 sessions at 8.7 SED per session, to reach 15 kJm^{-2} and 651 sessions at 0.2 SED per session. The median value was 71 sessions to reach the maximum recommended exposure.

The carcinogenic potential assessed of the sunbeds was assessed using the SCUP-h action spectrum. The SCUP-h effective irradiance for the beds varied between 0.02 and 1.58 Wm^{-2}, with a median value of 0.69 Wm^{-2}. Southern European sun has previously been quoted as having a SCUP-h effective irradiance of 0.595 Wm^{-2} [65]. Hence, using the median value, sunbeds can be said to be 1.15 times as carcinogenic as southern European sun. This value is similar to that calculated in 1997 [65].

The maximum SCUP-h weighted irradiance came from a stand up tanning unit and is substantially higher than that found by Moseley *et al*. In that study the maximum SCUP-h weighted irradiance from a stand up unit was 0.682 Wm^{-2} which led Moseley to the conclusion that stand up units had equivalent irradiance (a factor of 1.1) to southern European sun. Using the strongest unit as measured in the current work, the factor for comparison was 2.7 times as carcinogenic as southern European sun. This unit was a standard stand up unit with 160 W tubes in place and plastic diffusers in place. This is a significant and worrying rise in the SCUP-h weighted irradiance and suggests that the sunbeds in common use today have the potential to significantly increase the cancer risk for users.

Health and Safety assessment

In Dundee council health and safety officers carried out the assessments. Thus, through their authority, they were able to request proof of equipment and customer records etc. During the visits to Perth, there was no council health and safety officer attendance. Therefore it was only possible to ask questions during visits rather than requesting supporting information. Thus, the results from Perth may be biased in the business' favour.

One sunbed was found to be unsafe as the plastic covers to the tubes had large gaps in them and also had sharp edges. The screening of the units was found to be adequate in all but two commercial premises. In one case the bed was in the changing room of a gym and was not screened at all. In the other case a stand up unit was not screened and there was no circuit break to turn off the tubes if the door were opened. In two of the Dundee City Council premises there was inadequate screening of the sunbeds. In one these cases the sunbed booths were curtained but the curtaining did not reach the floor therefore providing questionable levels of privacy as well as protection (see figure 5.16).

Figure 5.16: Inadequate screening in one of Dundee City Council's premises

Most of the beds were clean and fluid was provided for cleaning of the units prior to use. Concerns were raised regarding the type of cleaning fluid provided and whether it should be the customer's responsibility to clean the beds. Although there is no legal requirement for ventilation, those premises that are said to have inadequate ventilation are those where the cubicle/room became very hot while taking measurements. These were judged to be a risk for people fainting. Of concern were the premises that kept no records of their customers' exposure. Of those that did keep a record the majority reported that they would not enforce the yearly limit by turning clients away but would only advise on safe limits.

Table 5.4: Health and safety assessment results

Inspection area	Assessment point	Number of premises where no evidence/inadequate/not offered
Equipment	bed safety	1
	stop buttons	0
	adequate screening	4
	hygiene	4
Housekeeping	cleaning	6
	fire precautions	0
Facilities	tanning lotions offered	31
	eye protection provided	3
	washing facilities	17*
	ventilation	21
Business	no clients per week	Minimum 2 Mean 100 Maximum 700
	member of sunbed association	40
Safety	staff training	15
	knowledge of hazards	43
	1st aid kit	9
	risk assessment for employees	46
	equipment maintenance and records	33 relied on contractors
Customer advice	medical	17
	skin type	24
	eye protection	13
	display advice	18
	take away advice	46
Records and controls	records kept	29
	length of session	35
	time between sessions	6 recommend 48h 21 recommend 24h
	total sessions per year	6 enforce no more than 20 10 enforce not more than 60
	recording of accidents	7

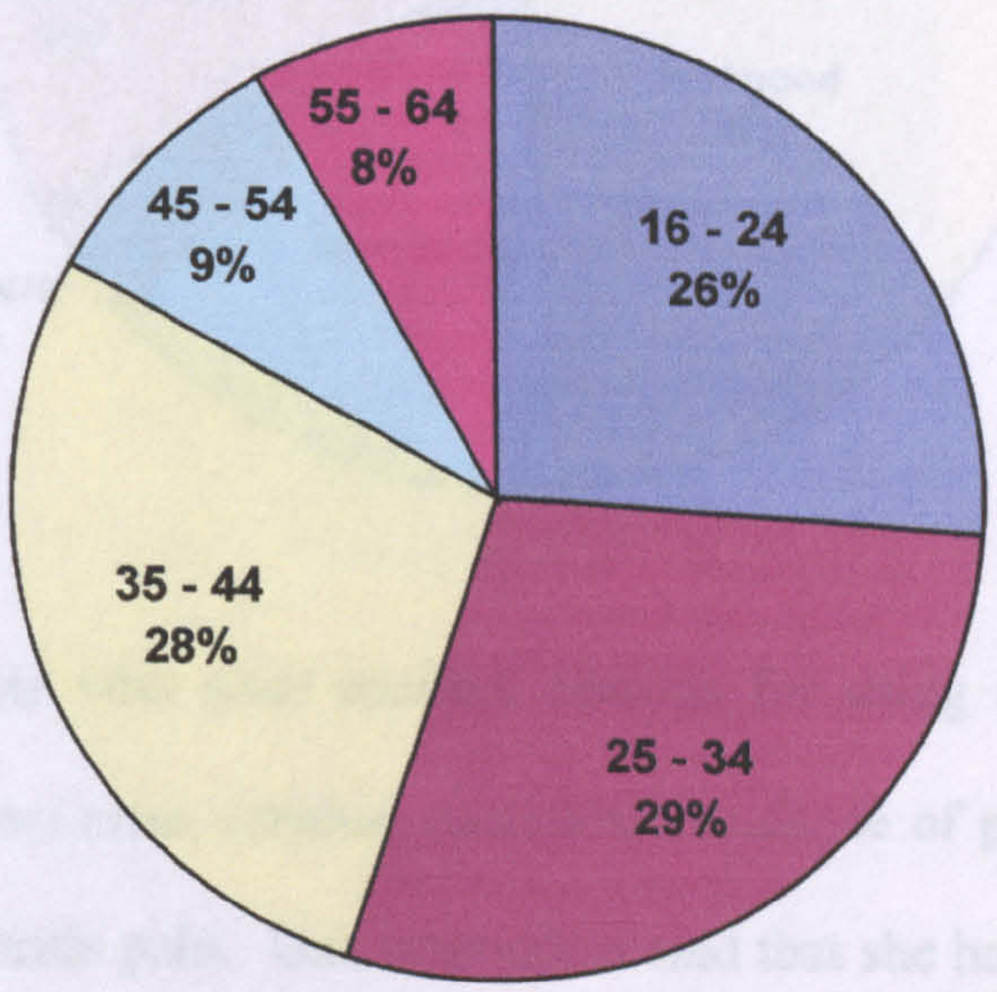
User Survey

There were 87 respondents to the survey, 14 of which were male and 73 female. It is likely that these respondents were the more concerned users, as completion of the questionnaires was voluntary. The majority of users were in the 25-34 years age

* The provision of a hand basin was not counted as washing facilities; only a full shower unit was regarded as adequate.

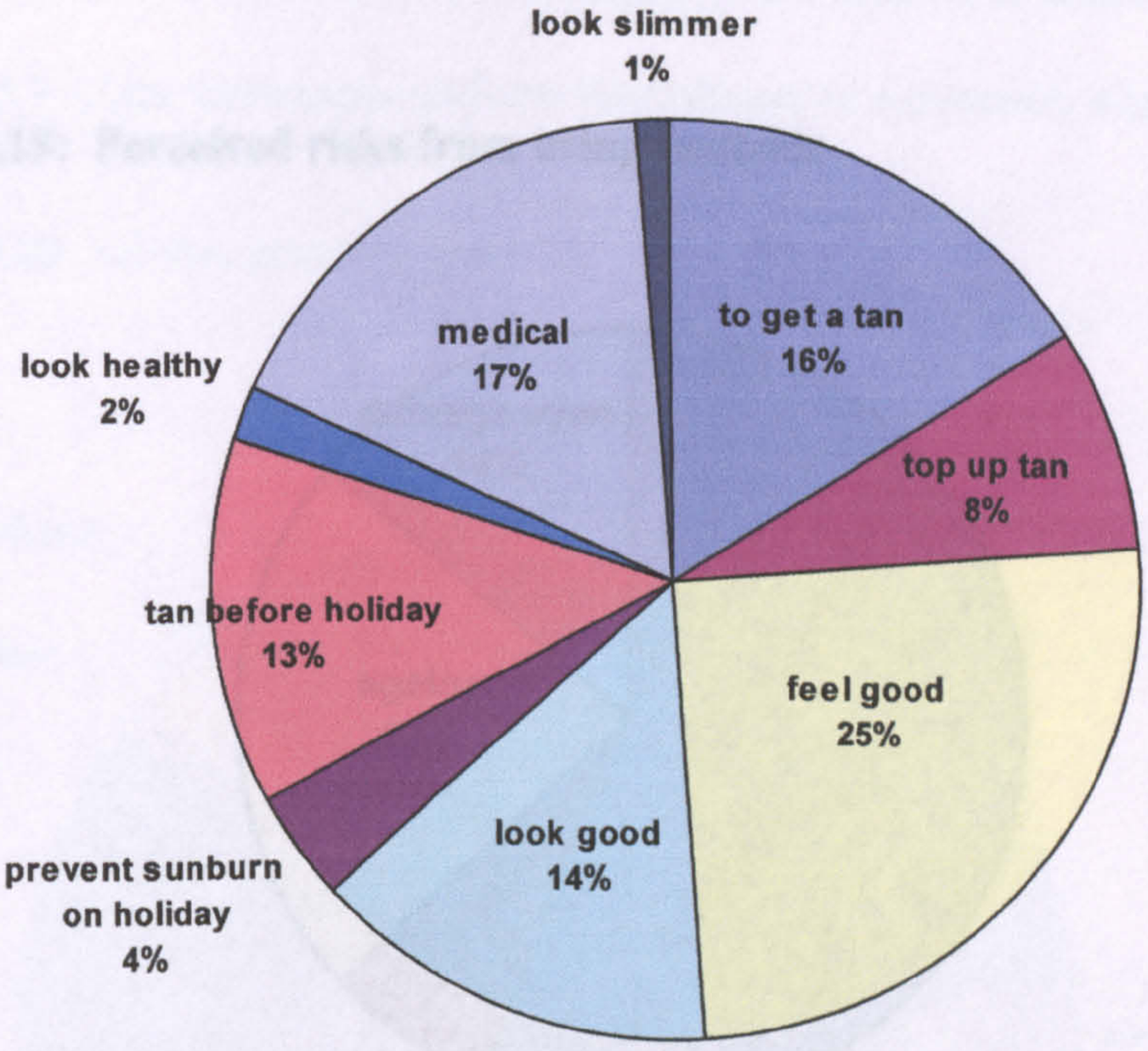
bracket (see figure 5.17). 51 % of the respondents started using sunbeds when aged between 16 and 24. Four people admitted to having first used a sunbed at age 15. 45% of the respondents had used sunbeds for between 0 and 3 years. 22% reported using sunbeds for more than 10 years.

Figure 5.17: Ages of users



31% of respondents admitted to visiting more than one tanning salon. Of these 41% used only two other salons and 28 % used more than 2 salons. 39% of users admitted to between 0 and 19 sessions in the last year, 35% said they had had 20-49 sessions, and 26% had had 50 plus sessions in the last year. One user admitted to 3 hours of use per week on one particular bed in one particular salon. Her effective exposure amounts to 3 kJm^{-2} in one week!

Figure 5.18: Reasons for using sunbeds

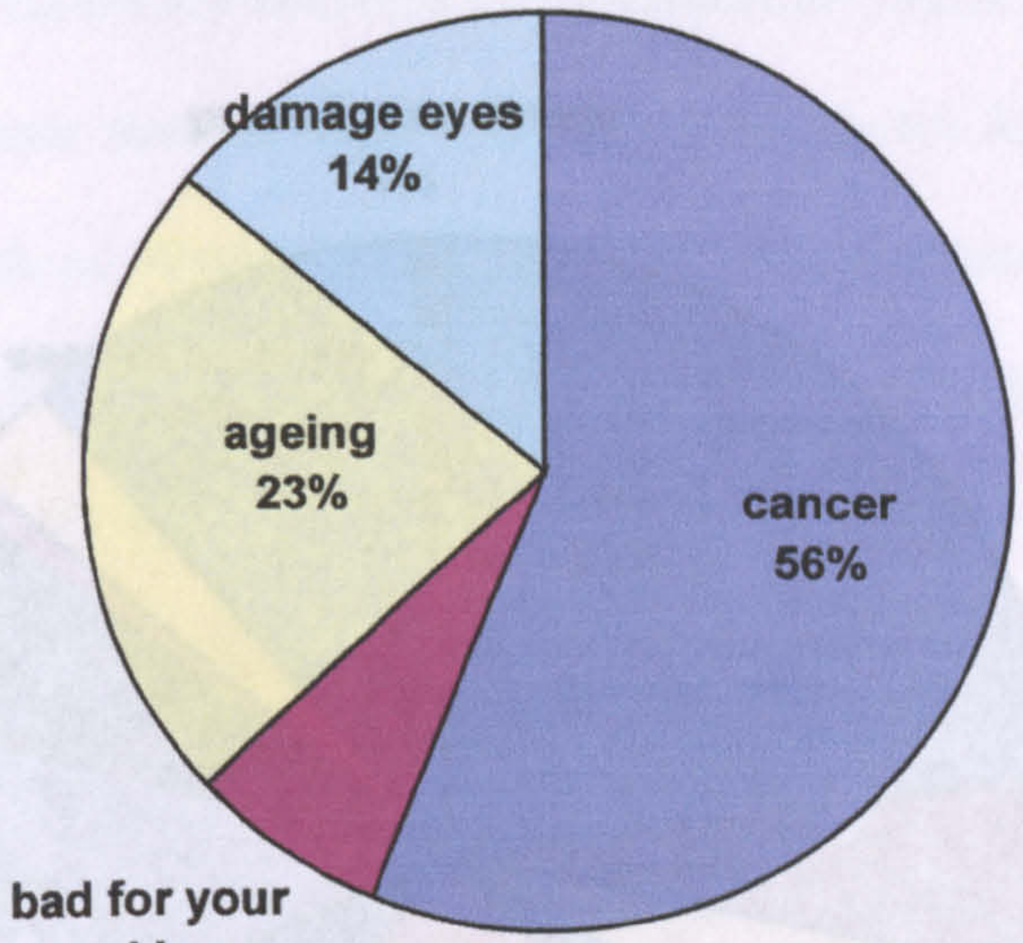


Among the 15 people who cited medical reasons for using sunbeds, the specific conditions quoted were acne, eczema, psoriasis, avoidance of prickly heat and relief from general and arthritis pain. One respondent said that she had completed a course of UV treatment in the photobiology unit and was continuing to use sunbeds as a self prescribed follow on from that treatment.

13 people stated that they thought there were no risks from using sunbeds. The rest stated that there were risks. The main risks cited are indicated in figure 5.19. In the category of damaged eyes, one person mentioned blindness and two mentioned eyesores. Basal cell carcinoma and melanoma were each mentioned by one person in the 'skin cancer' group. Sunburn was mentioned by two people in the 'bad for your

skin' category and changing moles by three people. The comment about moles was not, however, linked to a statement about skin cancer in any of the three respondents.

Figure 5.19: Perceived risks from using sunbeds

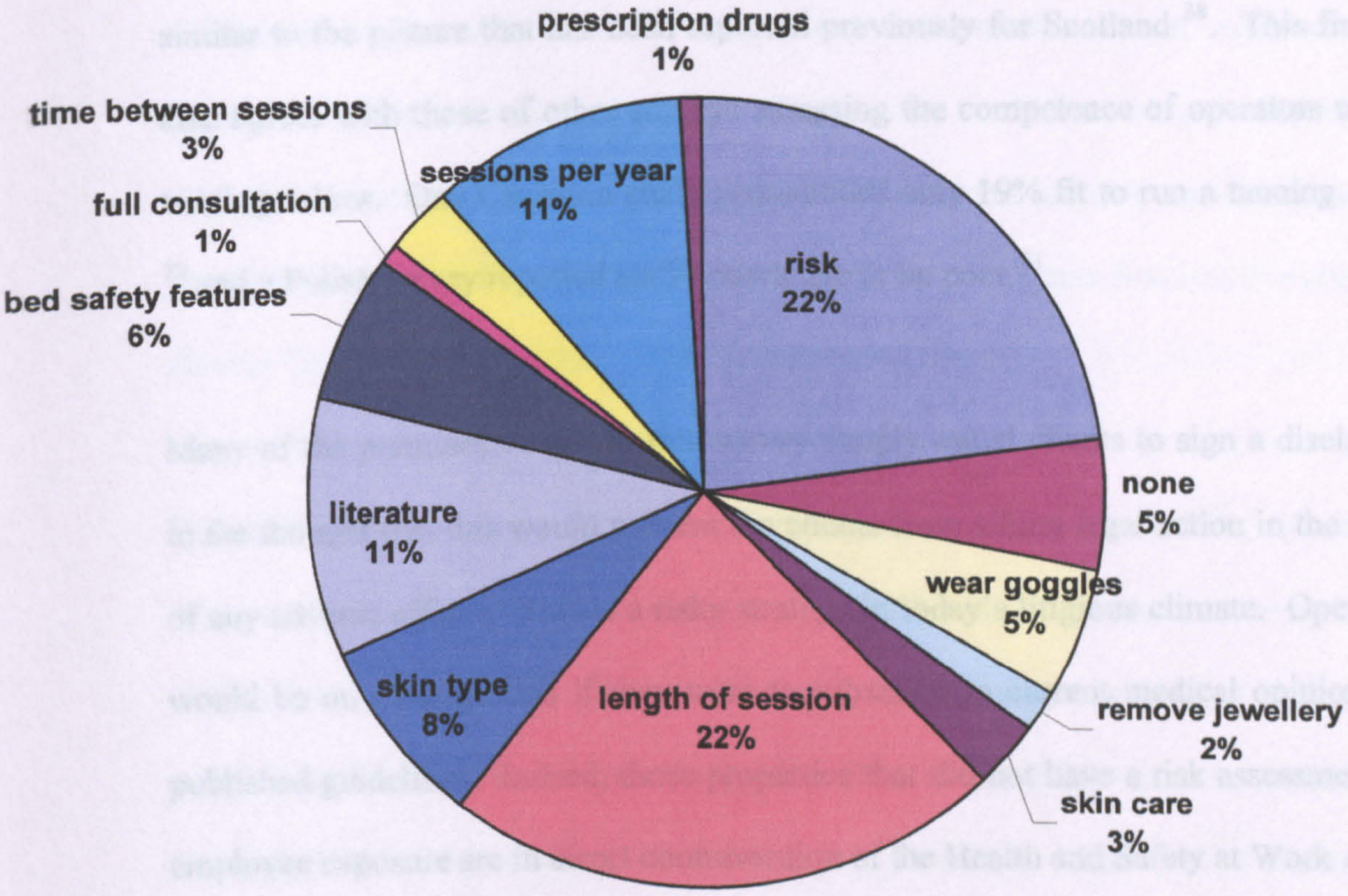


These figures indicate that the messages about the potential risks of sunbeds are not filtering through to the end users. Even where respondents recalled having received a full consultation before using the beds, they had only noted the risks linking sunbed use with ageing of the skin. Furthermore, 13 people said that they believe there to be no risks from sunbeds and 23 people admitted that they never wear goggles when using sunbeds. Seven said they only sometimes use goggles.

A worrying 7% of the users reported that they had had no advice at all before using the sunbed and only 7% had actually been advised to wear goggles. 12 people had only had literature to read regarding recommended usage and potential risks, seven of

who reported only posters to look at. Only one person reported a full consultation and only one had been recommended the correct 48 hours between sessions. Of the skin care advice, two people were recommended to use tanning accelerators, such as those sold in 62% of the businesses and one was advised to moisturise afterwards.

Figure 5.20: Advice given to users



4. Discussion

This survey represented an opportunity to put the instrumentation tested (see chapter 2) to the test. It was disappointing to discover that the instrument purchased for this work did not perform as expected. Thus the calibration performed was the same type as that used for radiometers. A separate calibration is required for each source

measured, which defeats the purpose and the benefit of this instrument to some extent. However, the instrument did allow spectral measurements to be made which is not always practical with a traditional spectroradiometer.

This work has revealed that a large number of the commercial properties offering cosmetic suntanning are not adhering to the guidelines stipulated by the HSE. This is similar to the picture that has been reported previously for Scotland [38]. This finding also agrees with those of other surveys assessing the competence of operators to run tanning salons. One Canadian study pronounced only 19% fit to run a tanning salon [72] and a Polish survey reported staff knowledge to be poor [73].

Many of the premises visited in this survey simply asked clients to sign a disclaimer in the thought that this would prevent the clients from taking legal action in the event of any adverse effects. This is a risky strategy in today's litigious climate. Operators would be on safer ground if they were to subscribe to current medical opinion and published guidelines. Indeed, those properties that did not have a risk assessment for employee exposure are in direct contravention of the Health and Safety at Work Act.

Of interest during this survey were the different approaches used by the two local authorities. Dundee City Council were much more proactive in their regulation of the premises and a number of findings of concern were followed up in the proceeding months. These included poor ventilation in a number of premises, the screening issues in the Council's premises and the ventilation and exposure control issues in the Supermarket. Perthshire Council were not able to dedicate as many man-hours to the

survey, and indeed they were unaware of the presence of sunbeds in a number of the properties visited.

This lack of standardised approach is surely replicated across the UK. Perth has one unmanned salon where users pay a machine for a token to use the sunbeds. This premises was effectively unregulated. There was a questionnaire on the machine selling tokens that asked for skin type and then would sell an exposure time appropriately but without the presence of someone, there is nothing to stop minors using the facilities. Conversation with the owner of the salon revealed that he had encountered many different levels of intervention and demands from local authorities all over the UK in which he had established sunbed centres.

The positive benefit that many users experience from using sunbeds [14,51], and the self treatment of skin conditions such as psoriasis [74] reveals a perceived need in our society for sunbeds. Although the epidemiological literature reveals that sunbeds are a risk factor for the development of melanoma, the prohibition of sunbeds is not justified given the societal impacts of other risky activities, which are not banned, i.e. smoking and drinking alcohol [35].

The question of licensing of sunbeds had recently been proposed in the Scottish Parliament. This idea should be encouraged and the current survey adds weight to the argument that these centres should be more closely regulated.

In 1996 Norris suggested that due to the risk of cancer from sunbeds, councils should remove them from their facilities [75]. This step has certainly pushed users from

regulated centres to the commercial sector [65] where the risks may be greater [76]. Thus the wisdom of this decision may be questioned. However, Dundee City Council were still operating sunbeds that did comply with the BS but the facilities were found to be lacking in terms of their screening, ventilation and by not providing sessions that were less than 1 SED. Hence, the removal of sunbeds from council premises *and* licensing of the commercial sector would ensure that all facilities operated in the safest possible manner.

Licensing would further protect children. During the course of this study there was an incident in Stirling, reported in the media [77], where two eleven year old boys had visited an unmanned salon in the city centre and had a total of half an hour each. The boys were later hospitalised when they developed severe burns. A Lanarkshire survey revealed that 21 children aged 8-11 (survey total 1405) had used a sunbed in a commercial premises [55]. In fact a number of respondents to this current user survey reported using sunbeds in commercial premises before they were 16. It is believed that risks of exposure are greater in children [78] and suggestions have been made, by researchers, that legislation should be introduced to protect children [79]. None of the facilities visited admitted to allowing children to use their sunbeds, but during the course of this research, operators were observed allowing young girls access to the units without checking identification.

Hand in hand with a more closely regulated approach should be better education. A suntan is often perceived as healthy [51] and attractive [52,80] where in fact any suntan is a sign of skin damage [19]. This message is not disseminating to the population that are regular users of sunbeds and their use is still regarded as safer than exposure to the

sun [36]. What is required is a more effective form of education [51,81]. The UV index was introduced to the UK in April 1999 [37] but there is little understanding among the general population of what this actually means. Although there are campaigns run to educate the public, the complexities of the situation regarding the effects of UVB compared to UVA, the use of sunscreens and the safety of sunbeds should be taught in schools in order to allow people to make informed choices. Intensive intervention programmes have been shown to reduce children's exposure in Australia [82].

There is widespread use of sunbeds to create a tan prior to going on holiday, as was reported in this study. Users often believe that this 'base tan' will protect them from erythema, however, a UVA induced tan actually provides little protection [18,83] and in fact this strategy can significantly increase the total UV dose received as less sun protection is then used [78,84]. The mean carcinogenic potential of modern sunbeds in Eastern Scotland has been shown by this study to be similar to that of southern European Sun and in some cases, much greater.

The majority of sunbeds do not comply with the British and European standard for cosmetic tanning units, hence the standard should be reviewed and updated in order to account for the strength of sunbeds that are now available. The BS stipulates that there should be sessions available that do not provide more that 1 SED for first time users. Less than half of the sunbeds surveyed had sessions available that were below this limit. In 1991 the International Non-Ionizing Radiation Committee of the International Radiation Protection Association suggested that manufacturers should 'supply a schedule of exposure and recommended maximum exposure durations based on the emission characteristics of the sunbed' [48]. Given that two thirds of

premises offering sunbeds already have their beds maintained under contract, it would make sense to enforce this guideline, thereby placing the onus on the manufacturer to appreciate and understand the spectral profile, ageing characteristics and strength of the sunbeds they supply. Advice could then be given on the length of sessions that constitutes 1 SED and operators could then comply.

Considering that a 'weak' bed can give as large a dose as a strong one, if the tanning session is long enough, it is clear that the magnitude of the spectral irradiance is somewhat irrelevant as what is important is the dose received during one session. Thus it is the length of the session offered that affects the total number of sessions that should be taken in one year. In this study all the available lengths of sessions on all the sunbeds in two local authority areas have been calculated.

The exposure limit of 15 kJm^{-2} erythemally weighted radiation per year suggested in the BS is based on the comparative risk of cancer for indoor and outdoor workers. This dose is half of the estimated difference between these two groups and is said to be a reasonable contribution for an indoor worker [85]. However, it is known that people who use sunbeds are also likely to engage in sun seeking behavior [52]; therefore they may exceed the dose for indoor workers by choosing holidays in equatorial regions etc. Once again, education is indicated in order to continue to inform individuals of their individual risk. The alternative approach would be to revise the exposure limit data on the basis of a person's likelihood to expose themselves to excessive natural sunlight, and reduce the yearly dose limit from sunbeds accordingly.

However, this approach is futile where there are no real controls over the number of sessions that people engage in during the course of one year. If manufacturers provided schedules then the cumulative dose could be monitored but this would be a complicated system to enforce particularly where sunbed operators appear to be unskilled. The fact that people use more than one salon would also allow them to greatly increase the total yearly dose received.

At present the best estimate that exists of the total safe yearly dose is the 15 kJm^{-2} erythemally weighted dose and according to the precautionary principle, given that the strongest sunbeds will allow a user to reach this dose in under 20 sessions, the BPG guidelines are justified. The Sunbed Association should also be pressurised into changing its advice from 60 sessions in one year to 20.

5. Conclusions

- The aims of this study were fulfilled. In Perthshire it was found that there were more premises offering sunbeds than those that the council were aware of. If local authorities are not aware of the existence of the sunbeds then they are unable to inspect the premises in order to fulfil their regulatory duties.
- Most modern sunbeds are stronger than they were reported to be in 1997 and they also have spectral distributions and strengths such that they do not fit into any category in the existing British Standard.
- Most premises do not fulfil the criteria set out by the HSE in terms of recommended operator guidelines.

- In order to safeguard the public, the existing recommended maximum number of sessions in one year (20) is concurrent with the precautionary principle.

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Chapter 6

Measurement of occupational UV sources and evaluation of hazards against existing regulations

Hazards associated with inappropriate use of UV sources

Summary

This chapter discusses some of the potential hazards of exposure to ultraviolet radiation sources in the workplace. The main focus of the chapter is the case of a hotel in central Scotland where inappropriate use of an UVC source caused an outbreak of skin and eye complaints among staff [1]. Results from spectroradiometric assessment of the light source concerned are presented with evaluation against existing exposure criteria.

As a result of this case, recommendations are made:

There should be greater safeguards in place to ensure that the correct UV tubes are fitted to flykillers and companies supplying UVC tubes should check the intended use more carefully. The fittings on UVC tubes should be altered in order to prevent the tubes being fitted to a unit intended for UVA tubes

1. Introduction

Ultraviolet radiation in the workplace

Ultraviolet radiation has several specific uses in non clinical environments e.g. arc welding, water and air sterilisation, in electric fly killers and for curing processes in

manufacturing, dentistry and for cosmetic tanning. In addition to these specific UV sources used in the workplace, inadvertent exposure to UV may also occur when visible light sources are used that contain some UV in their spectrum. Whatever the purpose of the UVR, the potential hazards posed to unprotected skin should be considered in order to avoid adverse effects to both photosensitive and normal skin. As mentioned in chapter 5, this is particularly important within the workplace, given the increasingly litigious nature of British culture.

Uses and effects of UVC radiation

UVC radiation is widely used for water, air and surface sterilisation [2,3] UVC radiation is germicidal because it can disable the DNA of microorganisms [4,5]. This property has been harnessed for water sterilisation in developing countries where clean water is not readily available. UVC can also be useful for sterilisation in operating theatres [6] and in air conditioning ducts to avoid health problems associated with 'office air' [7].

UVC can cause transient erythema and photokeratitis if skin and eyes are not suitably protected [8]. In all cases where UVC radiation is used at work, exposure should be avoided or protective masks worn, for example with arc welding. Photokeratitis is temporary photochemical injury of the cornea. It is a very painful condition where epithelial cells are destroyed due to exposure to UVC or UVB radiation [9]. The pain experienced is due to the fact that nerve endings are exposed. The short wavelengths of UVC penetrate only as far as the sclera and cornea of the eye and are therefore not implicated in the development of cataract [10].

Photosensitive skin can be susceptible to damage from UVC radiation. Atopic skin can flare on exposure to welding torches and has been reported to lead to hospitalisation [11]. There is also a report of polymorphic light eruption being revealed upon exposure to the UVC radiation in an arc-welding torch [12]. The emission of UVC during welding has been extensively studied [13].

Uses and effects of UVB radiation

Photodermatologists and phototherapy nurses could be exposed to UVB radiation during the course of treating patients. As already discussed, eyes are susceptible to UVB and exposure can lead to photokeratitis. Sunburn and carcinogenesis [14] are other adverse effects of UVB radiation. Except in the case of welders [10], exposure to UVB radiation is rare in the workplace unless such sources are used in error. A case was reported in the literature where UVB tubes were fitted to a flycatcher and caused photokeratitis among employees [15].

Uses and effects of UVA radiation

Cosmetic sunbeds (see chapter 5) contain mainly UVA radiation, which can present problems for tanning parlour workers if there is insufficient screening. The Health and Safety at Work Act requires that tanning parlour operators have undertaken a risk assessment for their employees in order to guard against occupational exposure [16]. It was discovered that most operators had not considered an employees' risk assessment[17]. There is no literature to the author's knowledge that discusses problems associated with occupational exposure to sunbeds. However, the literature detailing

the carcinogenic potential of sunbeds is comprehensive and suggests that excessive exposure could be hazardous [18,19]. This idea can be extrapolated to excessive UVA exposure in any workplace.

UVA radiation is used in electric fly killers: devices that are common in kitchens as they provide a hygienic and efficient way of trapping and killing insects and flies. Standard fly catching units use UVA radiation from fluorescent tubes to attracts insect onto an electrified mesh where they are killed and their bodies drop into a collecting tray [20]. This kind of trap removes the need for chemical deterrents or killers and thus also removes the possibility of cross-contamination of foodstuffs. These devices do not normally present hazardous levels of UVA radiation, however, there was a case reported in 1991 where staff in a meat processing factory suffered from erythema due to UVC tubes being fitted to their fly killer in error [21].

UVA penetrates further into the eye than shorter wavelength UVB and UVC and is linked to the development of cataract [22,23]. The lens absorbs virtually all UVA and therefore individuals that have had a lens removed due to a cataract (aphakes) are susceptible to retinal damage from UVA [24]. In severe cases this can lead to blindness [10]. Furthermore there is reported to be a two to four fold increased risk of intraocular melanoma with sunbed use [25].

Inadvertent exposure to UVR

As well as the potential problems caused by exposure to these clearly identified UV sources, hazards are also presented by sources with a UV component in their spectrum

that is not widely recognised. There are reported cases of the UVA component of photocopiers causing skin problems. One such report was of the aggravation of skin lesions caused by lupus erythematosus [26] and the other was of the exacerbation of polymorphic light eruption [27]. In both these cases the exposure to the UVA radiation could have been avoided with sensible precautions such as closing the lid of the photocopier, but the users were unaware that the machine emitted UVA.

In recent years there have been many new developments in lighting technology. The aim for engineers is to develop light sources that provide high quality, energy efficient lighting at low cost [28]. In 1990 70% of tungsten halogen lamps were shown to provide excessive UV [29] if workers used them for desk illumination for 4 hours per day, 5 days per week, at a distance of ~30 cm [30] and significant numbers of workers did so [31]. This hazard is eliminated if the sources are filtered against UVR [32]. Further concern has been raised about the UV emissions from fluorescent lamps [33,34] although this was refuted in a publication by the National Radiological Protection Board (NRPB) which concluded that these sources 'present neither an acute nor a significant chronic hazard' [35]. These concerns and findings emphasize the idea that as there are new developments in lighting technology there should be consideration given to the relative spectral distribution of the sources and thus the potential hazards presented to skin.

Potential problems of UV exposure to photosensitized skin

As well as potential hazards presented to normal skin from exposure to UVR whether recognised or inadvertent, there are additional hazards when skin has been

photosensitized. There are reports in the literature of severe phototoxic episodes resulting from excessive psoralen consumption. In one case a woman consumed 22.5 mg of psoralen [36] when eating celery root and was subsequently hospitalized for 48 hours following an half hour sunbed session [37]. In another report, cosmetic tanners had misused psoralen in order to enhance their tan and sustained extensive skin injury[38]. These cases are rare and normal dietary consumption of psoralens present no risk of photoxic injury [39].

UVR exposure limits

In the UK there are no specific laws covering exposure to non ionizing-radiation in the workplace. Instead, control of exposure falls under the umbrella of the Health and Safety at Work Act etc 1974 and the Management of Health and Safety at Work Regulations 1999. If Health and Safety Executive Inspectors wish to assess compliance with the aforementioned directives then published guidelines are followed. Several bodies; the National Radiological Protection Board (NRPB), World Health Organisation (WHO), International Commission on Non-Ionising Radiation Protection (ICNIRP)*, United Nations Environment Programme (UNEP) and the American Conference of Government Industrial Hygienists (ACGIH), all of whom have been involved in the development of and subscribe to these guidelines. Limits were first published in 1985 [41] and have been slightly modified and reaffirmed in several subsequent publications [29,42,43].

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* An independent scientific organisation chartered in 1992 by the International Non-Ionising Radiation Committee of the International Radiation Protection Association (INIRC/IRPA) [40]

All these UVR exposure recommendations utilize the S λ weighting function (normalized to 270 nm), which is based upon the acute hazard to skin and eyes from exposure to UVR. The guidelines state that in an eight hour period unprotected skin and eyes should not be exposed to more than 30 Jm^{-2} Sλ effective irradiance. This is thought to be ssubstantially below the levels that will produce clinically significant photokeratitis and also to provide only a third to a quarter of an MED [9]. Thus, it can be said that any exposure resulting in these symptoms has provided much more than this dose.

However, exposure limits do not consider abnormal skin and for individuals with specific photosensitivities, symptoms may occur below this threshold. Hence, if skin and eye problems do occur in a workplace it is necessary to consider the possibility of an aeroallergen, photoallergen or phototoxin in the environment.

Skin and eye problems at work

There are many reports in the literature of skin and eye problems in workplaces. Work related ocular damage is not uncommon [44]. One survey of patients attending an eye casualty unit in Scotland found that 21.7% of the cases were work related [45]. Common eye injuries are due to chemical burns or foreign objects in the eye [46,46]. One survey of a workers compensation database found that cooks, housekeepers, and food service workers have a higher risk of atopic conjunctivitis (relative risk, 3.2 to 7.3) compared with other workers, and also that the majority of the atopic conjunctivitis illnesses and burn injuries are associated with chemical exposures [46]. Although exposure of the eye may cause considerable pain, the human cornea appears

to be much less susceptible to the influence of phototoxic agents than the skin [47] so any agent that causes damage to the eye is likely to affect the skin as well.

Occupational dermatitis is not uncommon. Gawkrodger *et al* (1986) [48] reported the common occurrence of hand dermatitis in cleaners and kitchen workers in hospitals. Lammintausta *et al* (1982) [49] found that 1 % of hospital workers had hand dermatitis. This figure included, most commonly, cleaners, kitchen workers and nurses.

'Wet' occupations can increase the risk factor for developing hand eczema [50] and many cleaning products contain irritants and contact allergens [51,52,52]. Domestic and occupational products commonly contain fragrances, many of which are known to provoke contact allergy dermatitis [53]. Rarely, foodstuffs can cause allergic contact dermatitis [54,55,55,56,56] but as in the cases of irritant or contact dermatitis due to cleaning products, it is the hands that are most commonly affected.

<u>Outbreak of skin and eye complaints</u>

In August 2002, kitchen staff at a hotel in central Scotland experienced skin and eye problems believed to be related to their working environment. Symptoms included reddened, peeling skin on the face and hands and burning 'gritty' eyes. This prompted the company's occupational health department to instigate an investigation into the cause of this outbreak. Occupational health contacted Dr Forsyth, Consultant Dermatologist at the Contact Dermatitis Unit at Glasgow Royal Infirmary and requested that the work place be examined. After her inspection, Dr Forsyth asked

the Photobiology Unit at Ninewells Hospital in Dundee to examine the kitchen with a view to making radiometric measurements.

2. Patients and Methods

Clinical Cases

Out of 20 permanent kitchen staff, eight were reportedly affected. In April 2003, four of these were clinically evaluated at their place of work (patients 1-4). All presented with erythema (e.g. figure 6.1) and some peeling on their faces at the time of examination. The skin on photoexposed sites was clearly pigmented (figure 6.2). There was minimal involvement of the arms, hands and ears. Patients 1-3 also had active conjunctivitis at the time of examination.

Figure 6.1: Affected members of staff. The ski goggles (left) were provided by the management. The erythema on exposed areas is clearly visible.

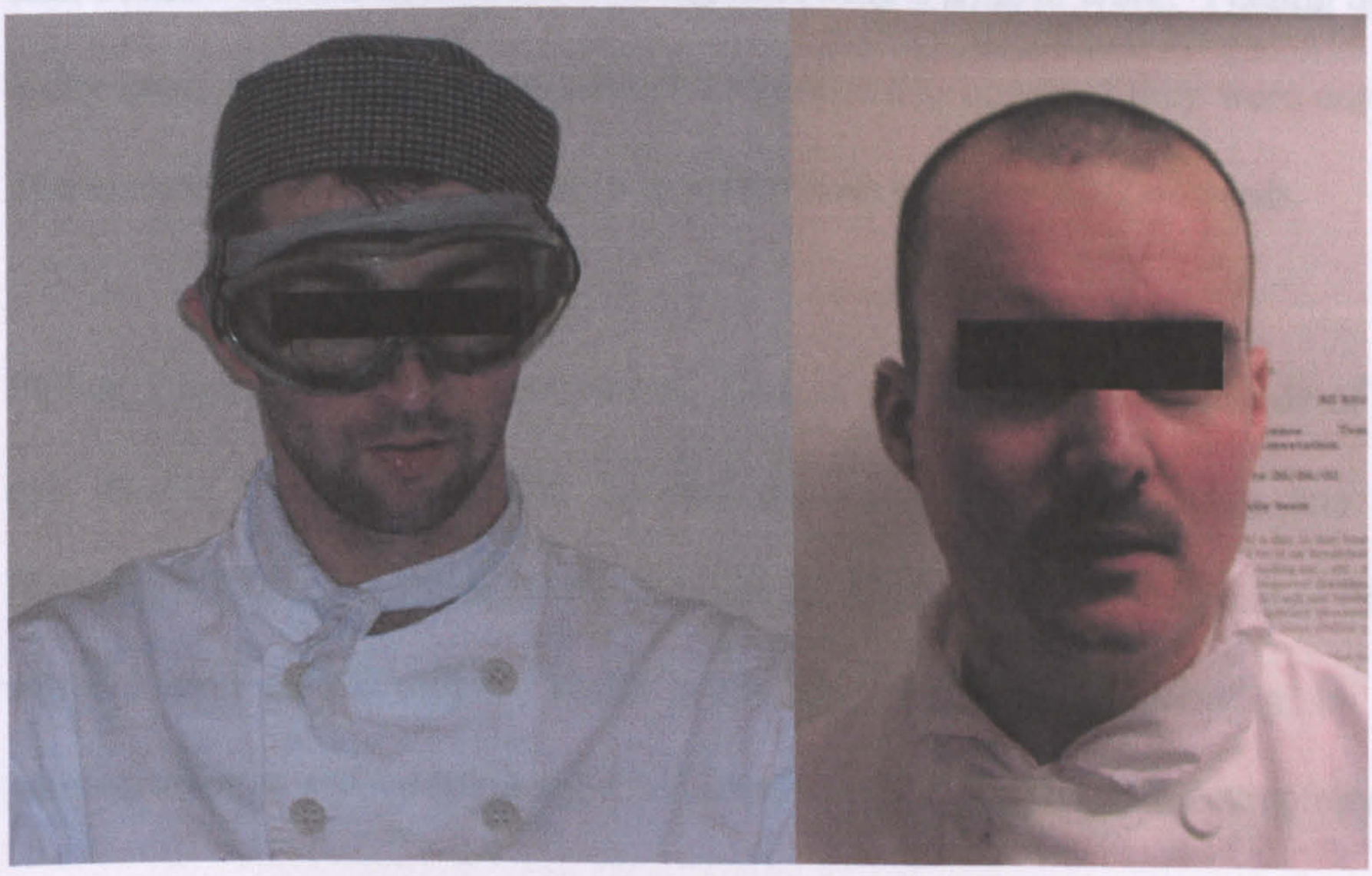
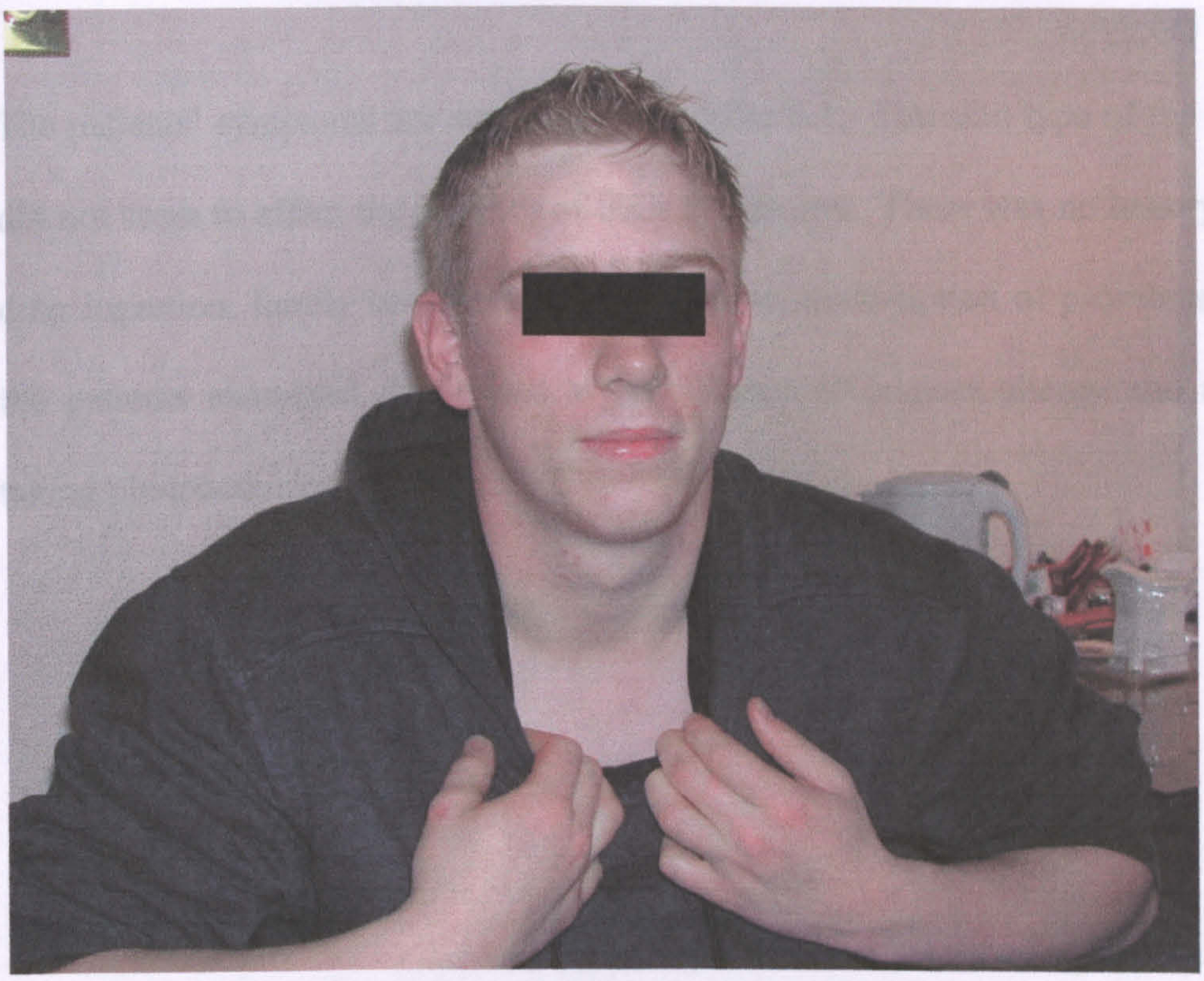


Figure 6.2: Patient shows pigmentation on photoexposed areas of skin



Patients 1 and 4 described the skin sensation as being very like sunburn Patients 1, 2 and 3 complained of stinging, burning or 'gritty' eyes. The staff reported that their skin became red and sore in the evening following a shift at work. Peeling developed 1 day later. Symptoms always subsided within a day or two if they were not at work. The members of staff had all begun to suffer from October 2002 onwards.

Patient 5 presented with no symptoms. He had suffered only one episode of skin and eye trouble the morning after he had painted the kitchen during one night in November 2003. All the lights were on in the kitchen and he had painted the ceiling using a long armed roller. Three hours after finishing the painting, he reported painful, swollen and weeping eyes, reddened and peeling skin. The symptoms cleared

over a five-day period off work. He has not had any recurrence of the symptoms since.

The patients' symptoms are summarised in table 6.1. The skin type of the individual did not seem to affect the severity of their symptoms. There was no history of atopy, drug ingestion, family involvement or excessive consumption of psoralens in any of the patients examined. None had a past history of contact allergy and none were taking photoactive medication.

Table 6.1: Summary of presenting patients symptoms

Patient	Age	Sex	Skin type	Shift worked	Marked tanning or erythema		Sore eyes	Precautions taken	Medical care sought	Days of work lost
					face	hands				
1	29	M	3	8-9 hours	✓		✓	Ski goggles	GP	None
2	19	M	2	8 hours	✓	✓	✓	None	GP	None
3	34	M	4	8 hour shift split by 2.5 hours	✓			None	GP	None
4	34	F	1	8 hour shifts	✓		✓	Ski goggles	Attended casualty on one occasion	None
5	44	M	3	7.5 hours painting the kitchen ceiling on one occasion	✓	✓	✓	None	Optician	5

Clinical Impression

The overall clinical impression was of conjunctivitis and sunburn-like erythema. The erythema could have various explanations. Flushing is a common cause for a transiently red face [57]. Estimated figures suggest that as much as 10% of the general population suffer from rosacea, which causes a characteristically reddened face and can increase the frequency of flushing. Patients with rosacea have also reported affected eyes, including dryness and chronic conjunctivitis [58]. The reddened face of seborrheic dermatitis may also involve secondary conjunctivitis but the estimated occurrence of this dermatosis in the general population is only 1-3% [59,59]. Atopic dermatitis, thought to affect 20% of the population, can cause a red face and the hands are also generally involved [60]. The face is a common site for contact or photocontact dermatitis to manifest itself. Allergens may be airborne or in direct contact with patients skin and airborne allergens are known to cause conjunctivitis [61].

It would be extremely unlikely for 24% of a workforce to have independently and simultaneously developed a dermatosis such as rosacea or seborrheic dermatitis. Eczema would not account for the ocular involvement. Given the prevalence of occupational skin disorders in kitchen staff, an irritant in the kitchen environment was suspected.

Interestingly, kitchen staff working split shifts (10 am – 2 pm and 5 pm to 10 pm) reported no symptoms or lesser effects than their colleagues working eight-hour stretches. This implied that the threshold dose for the irritant was only exceeded after four hours.

The involvement of the face, hands and eyes might have suggested an airborne irritant rather than one that required physical contact. Nevertheless, cleaning products were suspected, because irritants can be transferred from hands to face and eyes in affected individuals. Examination of the data sheets of all cleaning agents and sprays used within the kitchen pointed against an environmental phototoxin.

Hotel management had provided the staff with ski goggles to wear in order to protect their eyes. Only patients 1 and 4 chose to wear the goggles. They found that their skin involvement continued, although the eyes and area protected by the goggles was no longer affected. This evidence, along with the marked cut off of erythema on photoprotected skin, suggested that there might be a UV source in the kitchen. Thus, the decision was made to examine the light sources in the kitchen for hazardous levels of UV.

Kitchen Evaluation

The hotel boasted several kitchens but the affected individuals all worked in one area. This area was inspected and hazard measurements were made using an International Light Sλ weighted radiometer. Spectral measurements were also taken from several of the light sources in the kitchen using a Sola Scope 2000 meter with calibration traceable to NPL [62].

3. Results

The on site survey using the Sola Scope 2000 meter revealed that incandescent lamps, positioned on the food counter in order to keep the food hot, were found to emit some UV (see figure 6.3) but the Sλ meter readings confirmed that this was not enough to be hazardous to health. Similarly, overhead fluorescent lights were found to emit minimal UV. There were also electric fly killers placed around the kitchen. Two of these units (Rentokil) contained clear fluorescent tubes with no phosphor in evidence. The Sola Scope 2000 meter proved to have too little sensitivity at low wavelengths to detect any hazardous UV but the Sλ radiometer readings at 20 cm from the unit suggested that there was a hazardous level of UV emitted from these tubes (1 Wm^{-2}).

Figure 6.3: Emission spectrum from lamps on food servery

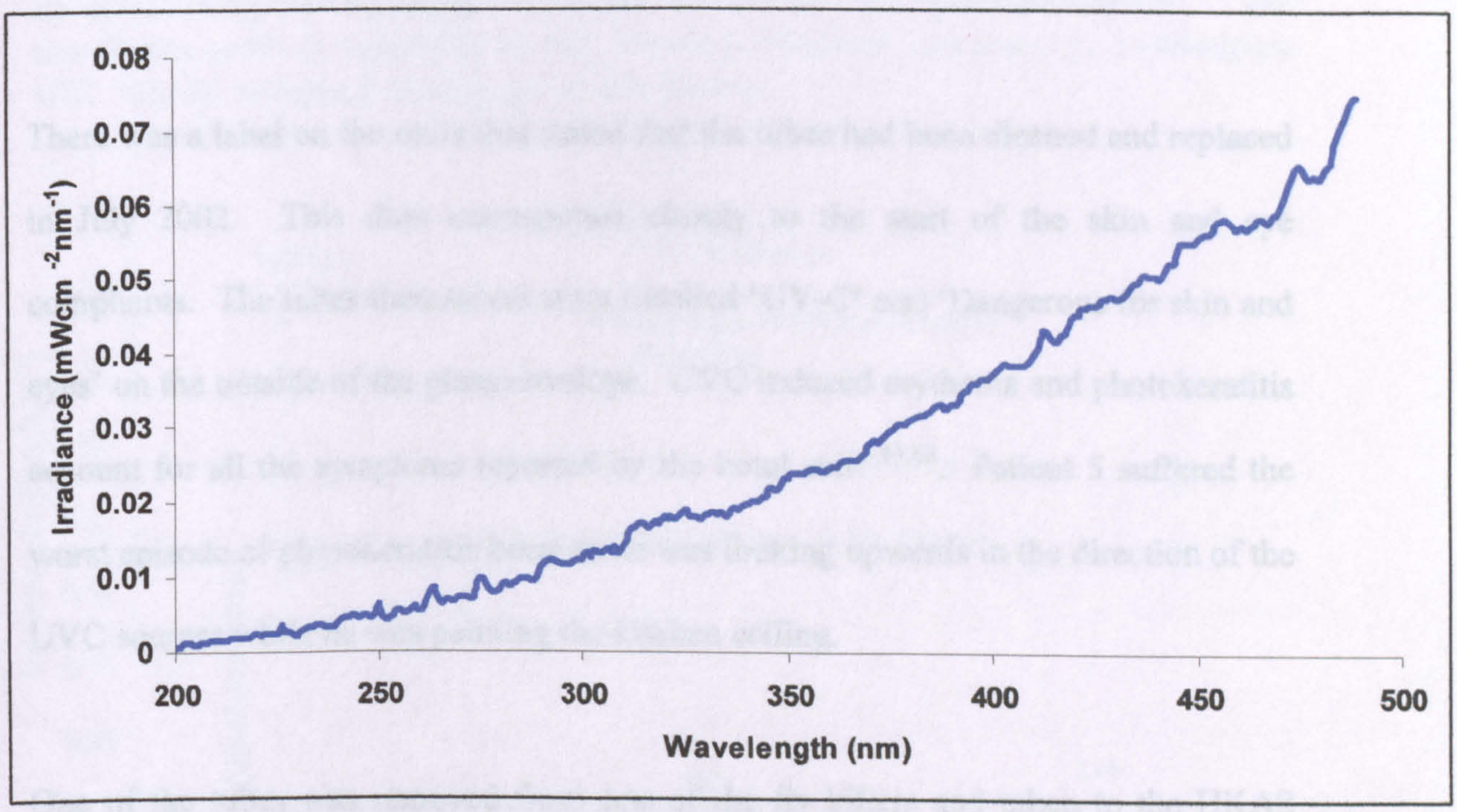


Figure 6.4: Position of one of the flycatchers on the kitchen wall

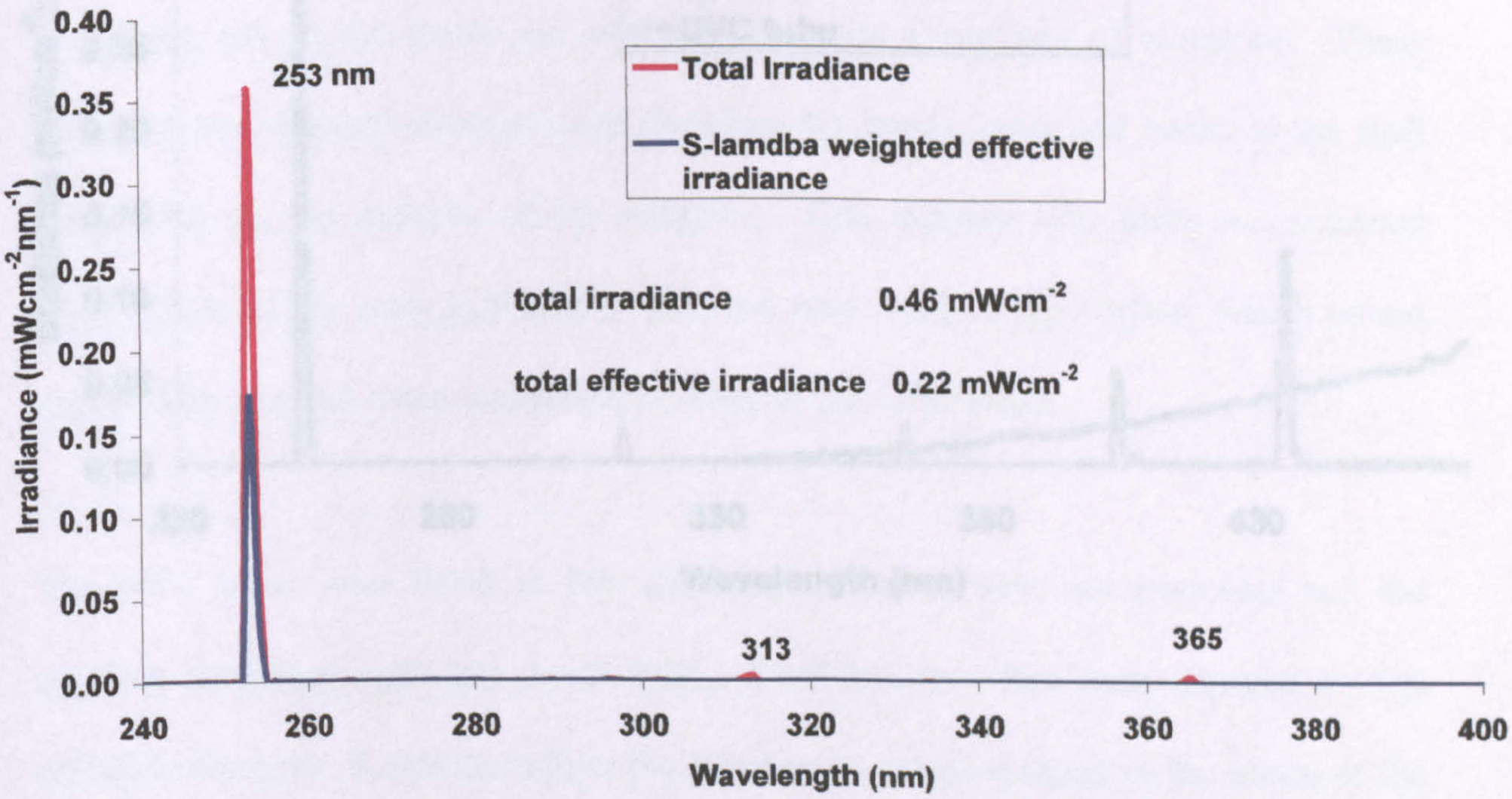
There was a label on the units that stated that the tubes had been cleaned and replaced in July 2002. This date corresponds closely to the start of the skin and eye complaints. The tubes themselves were labelled 'UV-C' and 'Dangerous for skin and eyes' on the outside of the glass envelope. UVC induced erythema and photokeratitis account for all the symptoms reported by the hotel staff [63,63]. Patient 5 suffered the worst episode of photokeratitis because he was looking upwards in the direction of the UVC sources while he was painting the kitchen ceiling.

One of the tubes was removed from one of the fly killers and taken to the UKAS accredited photo-laboratory at Ninewells Hospital, Dundee for accurate, spectroradiometric evaluation. Measurements were made at 30 cm from the Bentham

DM150 double grating spectroradiometer. This instrument has a cooled photomultiplier tube (-20°C +/- 1°) and its calibration is traceable to NPL. The tubes were found to emit strongly in the UVC region (100 to 280 nm) (see figure 6.5). Total irradiance from the tubes (200 to 600 nm) was found to be 4.6 Wm^{-2}. Application of the Sλ weighting function revealed an effective irradiance of 2.2 Wm^{-2}. Hence, the recommended upper level of 30 Jm^{-2} Sλ effective irradiance in eight hours on bare skin and eyes [42] would be exceeded after only 14 seconds.

The same weighting function can be used to calculate the time to the threshold dose for photokeratitis. This threshold is between 50 and 100 Jm^{-2} effective dose [64]. This dose would have been reached in 23-46 seconds.

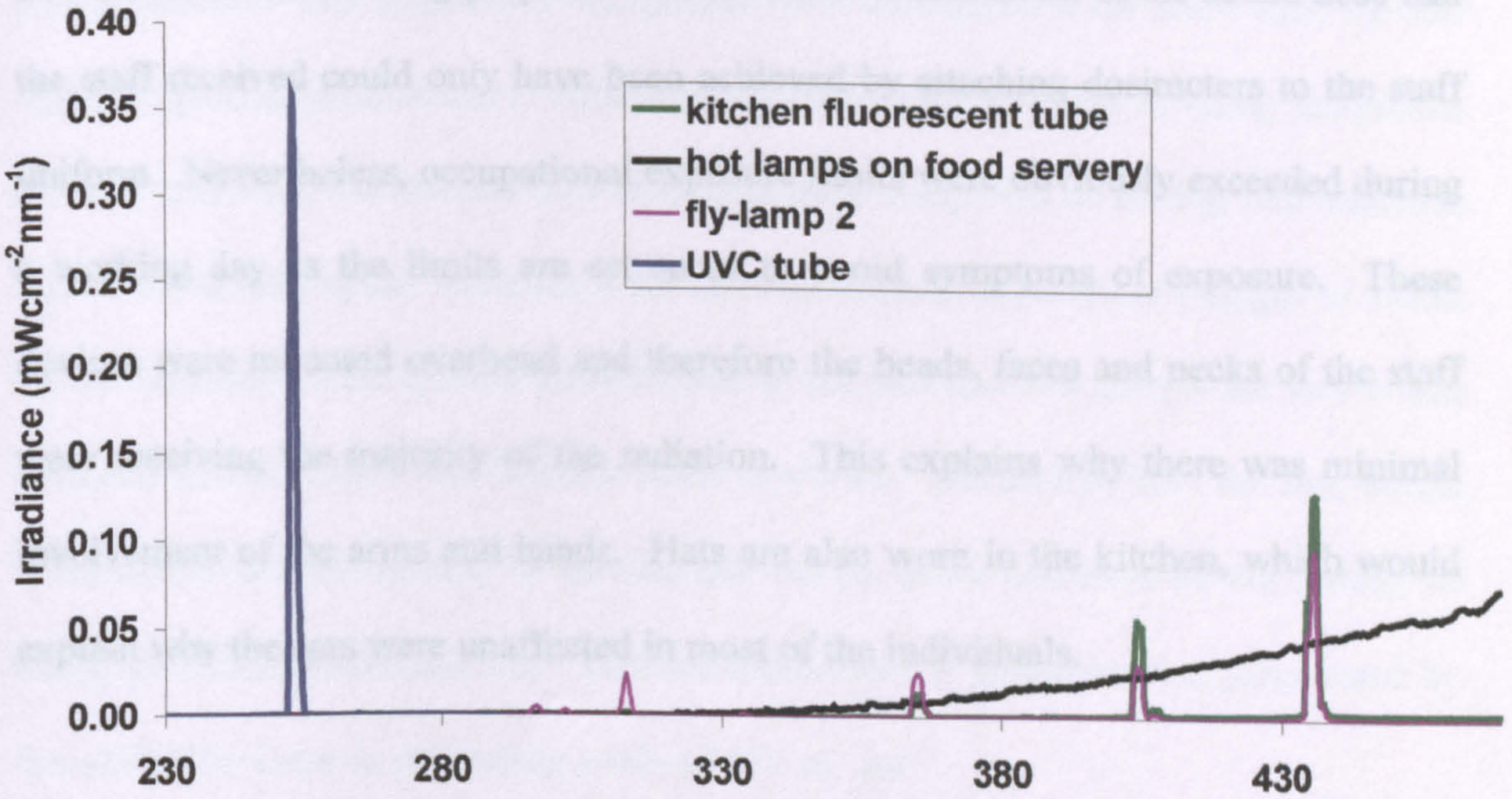
Figure 6.5: Emission spectrum from one of the UVC tubes in the flycatcher. This measurement was made using a double grating Bentham DM150 spectroradiometer boasting a cooled (-20 +/-1 °C) photomultiplier. The irradiance scale is traceable to the National Physical Laboratory, Teddington, UK. The Sλ weighted irradiance is also shown.



Erythemal weighting of the UVC tube spectra revealed that the erythemal effective irradiance was 4.5 Wm^{-2}. A source of this intensity would deliver one SED (100 Jm^{-2}) [65] in 22 seconds. For comparison- it would take >200 seconds to receive a similar dose at a distance of 30 cm from a TL01 unit consisting of 8 tubes.

The spectra obtained from the light sources in the kitchen are shown in figure 6.6. The relative intensity of the UVC tube is clear to see. This figure also shows the spectrum of the correct type of tube to fit in electric fly killers.

Figure 6.6: Spectra of the light sources found in the kitchen. The intense UVC radiation from the UVC tube can clearly be seen. The series labelled 'fly-lamp 2' represents the spectrum recorded from another flycatcher in the kitchen. This catcher had phosphor coated tubes fitted and represents no significant health hazard



4. Discussion

Although cases of occupational UVC irradiation are rare, previous reports such as this [15,21] indicate that confusion does arise with regard to the fitting of ultraviolet tubes to fly catchers. Of particular concern are the Rentokil electric fly killers that will fit either UVC or UVA tubes [1,21]. In order to avoid incidents such as this UVC tubes should be labelled more clearly and manufacturers should obtain more details as to the intended application before supplying tubes of this type. UVC tubes could also be manufactured with different fittings to other fluorescent tubes so that it would become impossible for end users to fit this type of tube in error.

The irradiance levels reported in the current investigation represent a 'worst case' scenario. Catering work involves moving about the workplace and generally looking down at food that is being prepared. An accurate measurement of the actual dose that the staff received could only have been achieved by attaching dosimeters to the staff uniform. Nevertheless, occupational exposure limits were obviously exceeded during a working day as the limits are set so as to avoid symptoms of exposure. These devices were mounted overhead and therefore the heads, faces and necks of the staff were receiving the majority of the radiation. This explains why there was minimal involvement of the arms and hands. Hats are also worn in the kitchen, which would explain why the ears were unaffected in most of the individuals.

The UVC tubes were fitted in July 2002 but premises were not inspected and the problem identified until late April 2003. Staff had therefore been exposed to this radiation for some 9 months before the tubes were acknowledged as the cause of the

skin and eye problems. The effects of long term UVC exposure in humans is not known. UVC radiation is known to be mutagenic [66,67,67] and causes erythema in much the same manner as excessive UVB irradiation does [68]. Whilst UVC photons are more energetic and therefore more damaging than longer wavelength UVB and UVA photons, they do not penetrate tissue as deeply. Therefore undesirable effects are confined to the outer tissue layers [69]. However, there is very limited data on long-term effects of human exposure to UVC because there is no follow-up of patients after the acute effects have been dealt with. This group of workers may provide valuable evidence of the long-term effects of UVC exposure in the following years. Dr Forsyth intends to monitor their progress on a regular basis over the forthcoming years.

Another issue highlighted by this incident is the lack of knowledge regarding UVR and its effects. The employees' symptoms went undiagnosed for some time despite visits to general practitioners. Although the tubes were labelled as being dangerous for skin and eyes, the kitchen staff described their symptoms as feeling like sunburn. However, no one in the company's occupational health department thought to check the UV sources in the kitchen possible due to the fact that few people are aware that artificial sources of UV can actually cause erythema. Ultraviolet from the sun, which is known to cause sunburn, is not thought of, by many members of the public, as being the same as artificial UV. This is a myth that has probably been perpetrated by the sunbed industry in promoting artificial UV as 'safe'.

There remains some debate over occupational exposure limits despite the fact that the relevant national and international bodies have been moving towards a consensus in

recent decades [43]. One aspect that is under debate is the maximum dose integration time to take account of prolonged exposure beyond 8 hours. This case cannot answer that question but what is interesting to note is that where employees were working split shifts there were, except in the case of patient 3, no symptoms evident. Patient 3 also only reported symptoms of the face. This employee had a 2.5-hour recovery period in the middle of an 8-hour exposure. This may mean that cellular repair processes had repaired the damage from the 4-hour exposure during this break, as is consistent with findings by Henriksen *et al* [70]. However, without having data from personal dosemeters from the entire kitchen staff, both affected and unaffected, it is impossible to know for certain the doses received and thus, quantify the effects. Personal dose monitoring was not possible because the UVC 'fly traps' were disconnected after the inspection visit to avoid any more harmful effects.

None of the employees in this case had specific photosensitivities. The exposure guidelines were also far exceeded, thus, this case does not point to any problems with the published exposure limits. The very high level of UV exposure received from these sources, given their proximity to head height, could have induced a very serious reaction in individuals with photosensitive conditions or those taking photoactive medication. The lack of knowledge of the effects of artificial UV radiation is of concern, particularly amongst health professionals such as those working in occupational health departments and in primary care.

5. Conclusions

- There should be greater safeguards in place to ensure that the correct UV tubes are fitted to flykillers.
- Companies supplying UVC tubes should check the intended use more carefully.
- The fittings on UVC tubes should be altered in order to prevent the tubes being fitted to a unit intended for UVA tubes.
- Occupational health professionals are ignorant as to the potential effects of artificial UV and should be educated as to the potential problems that can occur if normal *and* photosensitive individuals are exposed.
- These workers may provide useful evidence of the effects of long-term exposure to UVC.

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Chapter 7

Conclusions and further work

The impacts on skin of light from some artificial sources in the environment have been considered in terms of hazards, measurement, regulation and protection. The hazards of such radiation depend on the nature of the skin. Normal and photosensitive skin have been considered in context.

Pragmatic assessment of optical radiation hazards necessitates accurate spectral measurements. Diode array spectroradiometers may be useful for such measurements of UV sources. However, the Sola Scope (an instrument evaluated in chapter 2) should not be advocated for widespread medical use as the response of the instrument evaluated and the one purchased varied more than acceptable. Therefore a 'one size fits all' calibration could not be used. The calibration method adopted for measurement of sunbeds (chapter 5) is similar to that used for filtered radiometers and limits the use of this instrument. Thus there are manufacturing issues to be resolved.

The general assumption that action spectra can be used to predict responses to polychromatic radiation has been challenged for normal skinned individuals and those suffering with chronic actinic dermatitis (CAD). Solar urticaria was expected to not conform to a model of linear additivity and this was confirmed within the limits of the experimental methods employed.

Further research into the construction of action spectra in subjects with CAD is indicated. This could be achieved with narrower wavebands in phototesting and testing at more wavelengths. This would facilitate a more complex modelling of the response with potential fitting to another dose response function [1]. Furthermore, a full consideration of the uncertainties of thermopiles and their comparability to spectral measurements should be undertaken. This would be a considerable undertaking as the thermopiles used in Dundee have a very small area whereas the bench-based spectroradiometer employs flat plate diffusers that collect radiation over wide angles.

If these uncertainties were considered then the time to erythema from polychromatic sources may prove to be predictable using the erythemal action spectrum. The data presented in chapter 3 could be re-evaluated in terms of the discovered uncertainties.

Cosmetic preparations have been shown to have potential for protecting photosensitive individuals from visible light. However, these should be tested for their photoallergic potential as some cosmetics contain sun protection factors and suncreams are significant photoallergens [2].

Sunbeds available in commercial and council premises in Perthshire and Dundee are stronger than those previously measured [3]. The doses that could be received from sessions on these beds were considered and the recommended exposure limit of 20 sessions per year [4] was found to be prudent. A repeat of this work in

a few years would be wise as it would allow the trends in the strength of sunbeds to be monitored.

Most premises do not fulfil the criteria set out by the Health and Safety Executive in terms of recommended operator guidelines [5]. Thus licensing is a sensible proposal as it would ensure that guidelines are followed. A feasibility and financial analysis study of licensing is indicated.

The British Standard (BS) covering cosmetic tanning units was found to be outdated. Most of the sunbeds surveyed have spectral distributions and strengths such that they do not fit into any category in the existing standard. This should be revised and then premises could be forced to use units that comply with the BS under licensing regulations.

Finally, the case of a UVC tube being used in a fly-killer in a hotel kitchen emphasises the fact that there should be greater safeguards in place to ensure that manufacturers supply the correct light sources for their intended use. The ignorance of occupational health professionals as to the effects and use of UV radiation was also highlighted by this case. Education of such professionals would help prevent such cases occurring again. Follow up of the employees affected in this case may provide useful evidence of the effects of long-term exposure to UVC.

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Appendix 1

Publications

INSTITUTE OF PHYSICS PUBLISHING PHYSICS IN MEDICINE AND BIOLOGY

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The use of diode array spectroradiometers for dosimetry in phototherapy

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Abstract

An evaluation of two diode array radiometers, an UV spectroradiometer, Type SC-MP-A, from 4D Controls (Redruth, UK) and an USB2000-UV-VIS spectrometer from Ocean Optics (Duiven, NL), was carried out at the Photobiology Unit, University of Dundee. Three parameters of the instruments' performance were investigated, having been identified as the most likely sources of error in phototherapy dosimetry: (1) calibration, (2) stray light rejection, (3) angular response. An assessment was then made of the reliability of this type of instrument for dosimetry in clinical practice by measurement of a selection of phototherapy sources, in direct comparison with calibrated radiometers. Both instruments were found to have significant stray light levels (SC: 13% and USB: 39%). The use of stray light compensation and a high output calibration source improves accuracy to within acceptable limits. Angular responses were satisfactory: f_2 values ($\pm 60^\circ$) of 5.9% and 7.8% for SC and USB, respectively. The SC spectroradiometer is supplied as a calibrated instrument. Using the supplied calibration resulted in errors in measuring phototherapy sources of up to 44% in UVA. Alternative calibration reduced the error in measuring UVA and UVB sources to within 12%. The USB spectrometer was found to have insufficient responsivity in both UVB and UVA to provide reproducible measurements of most phototherapy sources.

1. Introduction

Within photomedicine, the need for accurate dosimetry of therapeutic UV radiation has long been recognized (Diffey 1978, Green *et al* 1992). If treatment times are kept to a minimum and accurately monitored then the risk of carcinogenesis is minimized, treatments can be optimized and there is also the potential for patients to transfer treatment centres without jeopardizing the course of their therapy. Any instrument that is used for dosimetry should measure to

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within 10% (Coleman *et al* 2000, Moseley 2001) because errors in dosimetry are clinically significant and may lead to painful erythematous reactions (Moseley *et al* 1993, Hansen *et al* 1994). There are currently three different options for measuring UV radiation for health hazard or phototherapeutic assessment, namely spectroradiometers, personal dosemeters and filtered radiometers (Driscoll 1993).

Spectroradiometry is beneficial because it allows the operator to resolve the spectrum of the lamp being measured. If spectral data are collected then there is the potential to apply different action spectra to the output of the lamp. Therefore, the risk of exposure can be assessed for patients with different skin conditions that exhibit different spectral sensitivities. This idea can also be extrapolated to other light sources in order to give advice to photodermatoses patients on exposure levels to all types of light. Absolute spectral irradiance measurements can be achieved at an uncertainty level of 4% in spectroradiometry (Kostkowski 1997) but the technique involves expensive, bulky and complex equipment and can require a large period of time to take measurements. Within a busy treatment centre, transporting bulky equipment to measure outputs from phototherapy sources is impractical.

Studies of personal phototherapy source dosimetry have been conducted, primarily using polysulphone film badges (Fanselow *et al* 1987, Jekler *et al* 1990, Knuschke and Barth 1996) since their introduction as personal dosemeters for UV radiation (Davis *et al* 1976). These badges can provide useful information regarding the distribution of phototherapy radiation over a patient's skin. Other commercial personal dosemeters incorporating UV sensitivity are available. These are generally based on solid state detector technology, e.g. the sp3 (Tunbridge Wells, Kent) 'Sunwatch'™ which is based on a solid state gallium nitride detector.

Output measurements from UV treatment cabinets and lamps have traditionally been carried out using filtered radiometers, calibrated against sources similar to those being measured. These broad or narrow band radiometers do have limited accuracy and cannot resolve the spectrum of the lamp of interest but by following guidelines for meter calibrations against a spectroradiometer (Norris *et al* 1994; Diffey and Hart 1997), doses can be measured to within 10% with relative ease. This type of meter is currently the preferred option for health hazard assessment (Driscoll 1993).

The relatively new technology of the diode array spectroradiometer provides potentially the perfect answer to the trade off between spectral data collected with a cumbersome instrument and the ease and speed of the filtered radiometer: a portable instrument that will acquire spectral data (Ridyard 2000). An example of the optical layout of such a spectroradiometer is shown in figure 1. After incoming radiation has been split into its constituent wavelengths by a diffraction grating, a series of fixed, silicon photodetector pixels transduce the radiation into an electrical signal. As all the pixels have fixed positions, it is possible to predict the wavelengths that will fall on each pixel and a spectrum can therefore be determined using appropriate software. Before this type of instrument becomes widely used in the medical field, it is important to assess the limitations of their use and the reliability and accuracy of the data collected from them. If diode array instruments are to become the dosimetry instrument of choice in the future and filtered radiometers are to be usurped then the same requirements for accuracy should apply in both cases.

During 2001 and 2002, two diode array instruments, from different manufacturers, were evaluated at the Photobiology Unit, University of Dundee. This is a well-equipped laboratory with ISO 9001 registration and standards traceable to the National Physical Laboratory (NPL) (Teddington, UK) spectral irradiance scale. A number of investigations were carried out to assess the performance parameters of these instruments. There are three areas of performance which were investigated as these were identified as, potentially, the largest sources of error in using the instruments—calibration, stray light rejection and angular response.

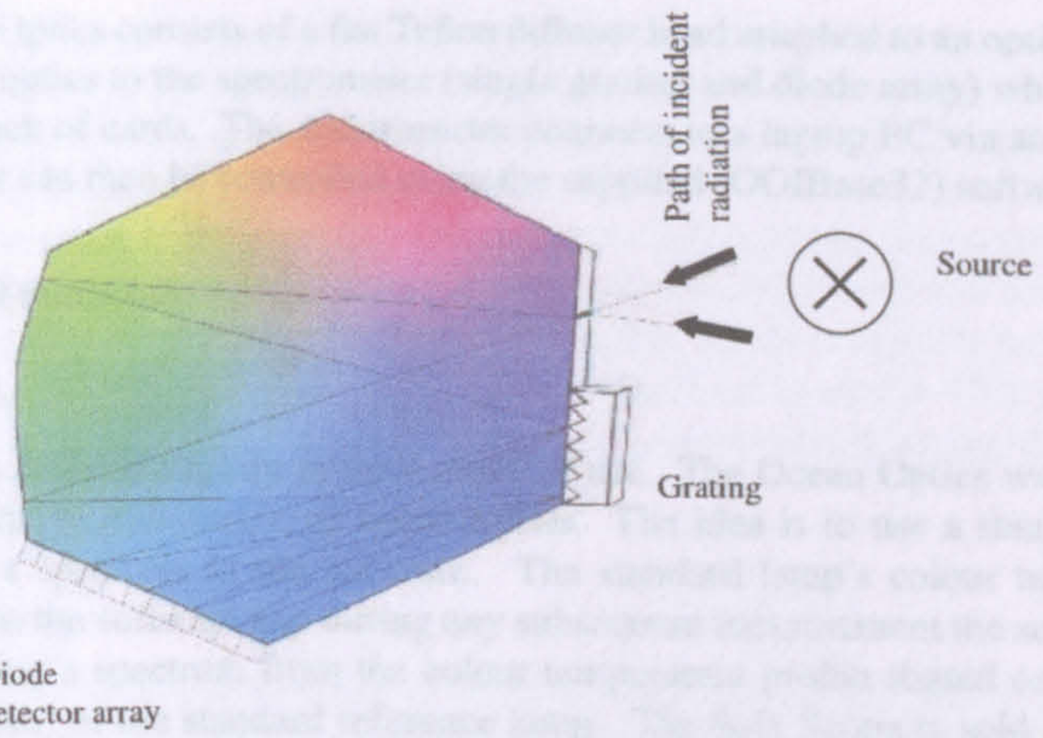

Figure 1. Diagram showing the optical layout of a diode array spectroradiometer. (Graphic courtesy of 4D Controls.)

(This figure is in colour only in the electronic version)

The calibration of the instruments must be traceable to national standards and should agree with a calibrated, double grating, bench based spectroradiometer (Coleman *et al* 2000). This ensures reliability of readings and facilitates transfer of doses between centres.

In the case of diode array instruments, stray light is the radiation that is detected by the 'wrong' pixel for the wavelength of the radiation. This phenomenon is common to spectroradiometric systems although in the case of most bench based spectroradiometers, two successive gratings are used to improve the wavelength selection. These diode array instruments are single grating, portable instruments and as such would be expected to have poor stray light levels which will affect the overall calculated dose for any phototherapy instrument.

As phototherapy sources are diffuse, wide angled and non-directional, it is important that any instrument for use in photomedicine will detect radiation at all the input angles from which radiation will be incident on the skin. Phototherapy cabinets are often 360° sources and the expectation of radiometers is that they have an error margin (f_2 value) of 10% or better (Pye and Martin 2000, Moseley 2001).

In order to give an assessment of the reliability of this type of instrument in clinical practice, the calibration of the instrument and the influence of its angular and spectral responses should be checked by measuring a number of phototherapy sources against calibrated radiometers or a spectroradiometer.

An UV spectroradiometer, Type SC-MP-A, from 4D Controls (Redruth, UK) (hereafter referred to as Sola Scope) and an USB2000-UV-VIS spectrometer from Ocean Optics (Duiven, NL) (hereafter referred to as Ocean Optics) were both evaluated at the Photobiology Unit, University of Dundee.

The Sola Scope is a self-contained spectroradiometric instrument which consists of a hand held 'sensor head' with a domed Teflon diffuser forming the input optics to the single grating and diode array, all contained in one compact box. The sensor head then connects to another hand held unit containing the software, control keypad and a display panel to enable spectra of measured lamps to be visualized. Data from the Sola Scope can be easily uploaded to a PC spreadsheet for analysis via the supplied (Sola-Term 2000) software.

The Ocean Optics consists of a flat Teflon diffuser head attached to an optical fibre which forms the input optics to the spectrometer (single grating and diode array) which is a unit no bigger than a pack of cards. The spectrometer connects to a laptop PC via an USB port and the spectrometer can then be controlled using the supplied (OOIBase32) software.

2. Methods and materials

2.1. Calibration

The instruments differed slightly in their mode of use. The Ocean Optics was designed for use as a comparative radiometer, or spectrometer. The idea is to use a standard reference lamp to record a spectrum in the software. The standard lamp's colour temperature can then be input into the software and during any subsequent measurement the software derives the measured lamp's spectrum from the colour temperature profile (based on a black body emission spectrum) of the standard reference lamp. The Sola Scope is sold as a calibrated instrument that will give readings in absolute units, traceable to NPL.

To set the wavelength scale on the Ocean Optics instrument, a low-pressure mercury Pen-Ray lamp was used. The position of eight known spectral lines (between 253.65 nm and 579.07 nm) and the pixel that detected these lines were analysed by linear regression and the regression coefficients were input into the software. The wavelength scale was then calculated by the software. For absolute unit calibration, the Ocean Optics instrument was calibrated by the investigator against a 1 kW incandescent quartz halogen lamp (designated type FEL) calibrated at NPL. The lamp was allowed 30 min warm-up time and was run at a current of 8.33 A. From the response of the Ocean Optics, a calibration template was derived at each wavelength such that

$$\mathrm{SF}_\lambda = \frac{E_\lambda}{R_\lambda}$$

where SF_λ is the sensitivity factor at a given wavelength, E_λ is the lamp irradiance at the same wavelength and R_λ is the instrument response at that wavelength.

The Sola Scope's in-built calibration factor is derived by the manufacturer from a deuterium lamp. However, the software allows a custom calibration file to be created by recording a spectrum of a standard lamp, in the same way that the calibration template was created for the Ocean Optics. A calibration of this type was performed using the same 1 kW FEL lamp. The wavelength of the instrument was checked by sampling the spectrum of a low-pressure mercury lamp.

2.2. Stray light

Stray light levels were assessed in these instruments by the use of a xenon arc lamp, filtered for infrared radiation (IR) with a $H_2SO_4 \cdot CuSO_4$ solution and a cut on filter (WG305, Schott). The lamp was allowed at least 15 min to stabilize before the spectra were measured by the diode array instruments. The advantage of using a source with a broad spectral output is the fact that stray light contributions from longer wavelengths, which may be detected as short wavelengths, can be identified more easily than if a monochromatic source or a source with clear emission lines is used. As the filter has a well-known transmission profile, the stray light present in the recorded spectra can be expressed as a ratio of the signal level at a given wavelength (Kaye 1981).

There is a method recommended to correct the stray light in the signal recorded from the Sola Scope. This method involves using an orange filter which only transmits radiation

above 355 nm. The filter is placed over the input optics of the Sola Scope and the resulting irradiance profile is then subtracted from subsequent scans. This procedure must be repeated before each lamp measurement because there will be a different stray light 'profile' according to the spectral distribution of the lamp of interest.

There is no method to remove stray light from the Ocean Optics instrument although the same procedure may be applicable. The calibration derived from the 1 kW FEL lamp should calibrate the stray light levels in the signal although this will be subject to some error due to the differing stray light 'profiles' of the calibration source compared to what is measured. A recording of the dark spectrum was made before each measurement run and the dark current or noise is, therefore, subtracted from each spectrum.

2.3. Angular response

A measurement of the angular response of the instruments was made using a xenon arc lamp. The lamp (as used for assessing stray light) was allowed 15 min to stabilize after ignition. The instruments were positioned with the input optics at the centre of rotation of a turntable. The turntable is marked at 1° intervals. The turntable was moved manually and a spectrum was recorded at each 5° step over the interval ±60°.

The angular response of the Sola Scope was measured in the planes parallel to the grating and perpendicular to the grating. The response of the Ocean Optics was considered in one orientation only as there is an optical fibre coupled to the diffuser so that all radiation is scrambled within the fibre.

A value (f_2) for the cosine response can be calculated as

$$f_2 = \frac{\sum \left| 1 - \frac{R_\theta}{R_0 \cos\theta} \right|}{n} \times 100$$

where θ is the angle of measurement, R_0 is the response of the instrument at 0°, R_θ is the response at the angle of measurement and n is the number of measurements.

2.4. Measurement of phototherapy sources

Any instrument intended for use in phototherapy dosimetry should be able to record an accurate dose (to within 10%), of any phototherapy lamp. A number of different sources in the unit were measured, ranging from whole body treatment cabinets to single fluorescent tubes. These measurements were made at a nominal distance of 30 cm from the source and at least 5 min was always allowed for the output from the lamps to stabilize.

Measurements were made in direct comparison with either the unit's IL1400 radiometer (Able Instruments, Reading, UK), which has attachments for measuring both UVA and UVB; or a bench based double grating spectroradiometer (Bentham DM150). In accordance with guidelines, the radiometer was calibrated against sources with similar spectral outputs to those to be measured (CIE 1984), in direct comparison with the Bentham spectroradiometer.

The calibration of the Bentham is traceable to NPL and has an estimated expanded uncertainty at the 95% confidence level, of 5.72% in UVB and 3.48% in UVA. These uncertainties have been calculated in accordance with NPL guidelines (Bell 2001) and include consideration of the uncertainty in the calibration sources used, alignment errors and uncertainty in the current from the cooled (−20 °C ± 2 °C) photomultiplier tube. The transfer standard for UVA radiation measurements (315–400 nm) is a 100 W frosted glass tungsten lamp, and a 30 W deuterium discharge lamp is used as a transfer standard for UVB (280–315 nm).

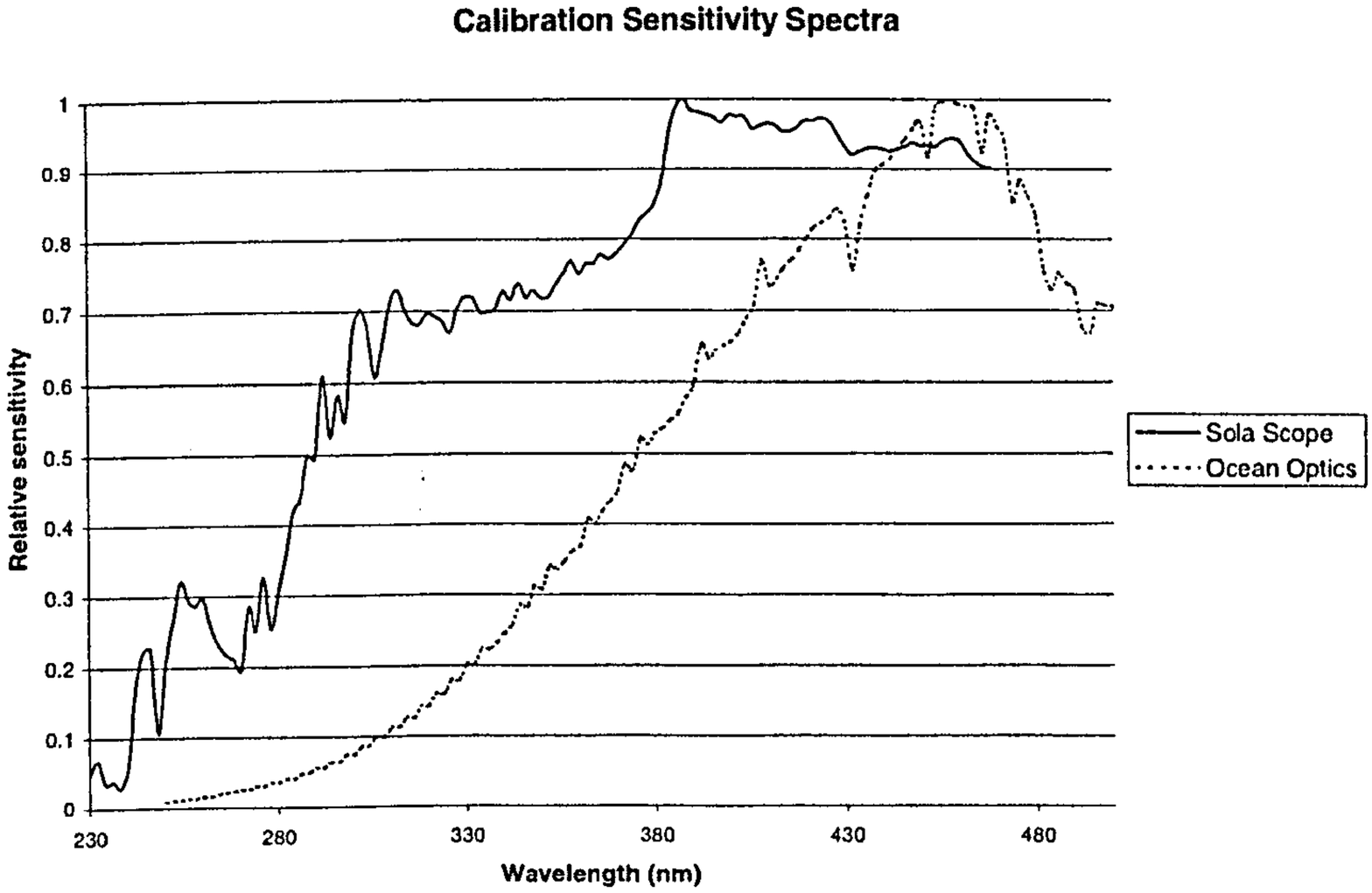

Figure 2. Graph showing the relative spectral responsivities of both the Ocean Optics and the Sola Scope.

Table 1. Wavelength error of Sola Scope.

Spectral line (nm)	Recorded position (nm)	Error (nm)
253.65	253.5	−0.15
313.10	313.0	−0.10
365.00	365.0	0.00
404.70	404.5	−0.20
435.80	436.0	0.20

Table 2. Stray light ratios from the diode array instruments. The percentage value expressed is the ratio of the signal at 250 nm to that at 430 nm.

Instrument	Without compensation or calibration	With compensation or calibration
Sola Scope	13%	2.0%
Ocean Optics	39%	0.4%
Bentham DM150 Spectroradiometer	<0.001%	<0.001%

3. Results

3.1. Calibration

The calibrations of both instruments reveal significant differences in the relative responsivities (see figure 2). Wavelength error for the Sola Scope is shown in table 1 and was satisfactorily small to be considered negligible. There was a significant amount of noise in the signals from both instruments.

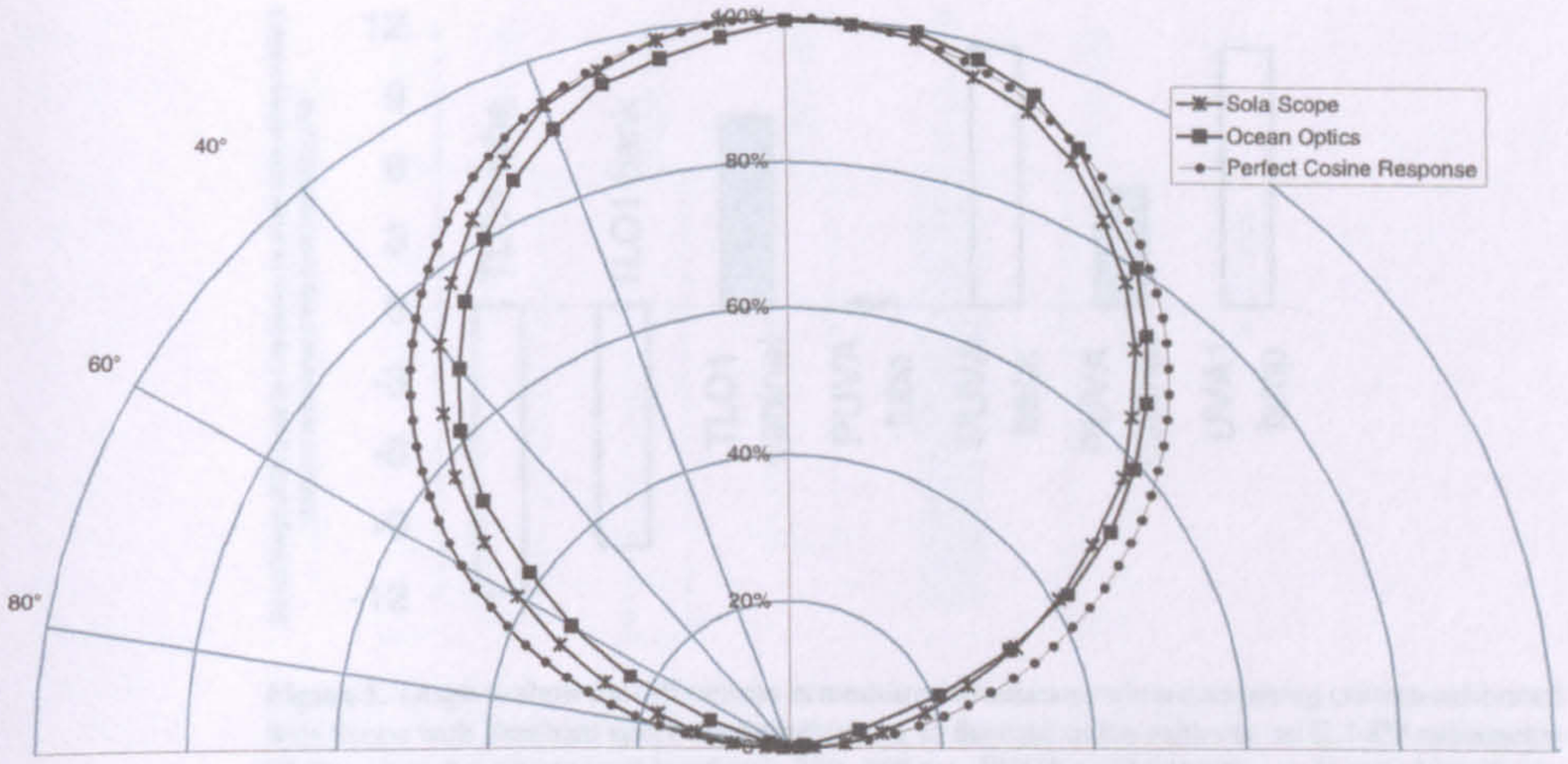

Figure 3. Polar plot to represent spatially the cosine responses (as a percentage of the maximum) of the Ocean Optics and Sola Scope at incident radiation angles from 90° to −90°.

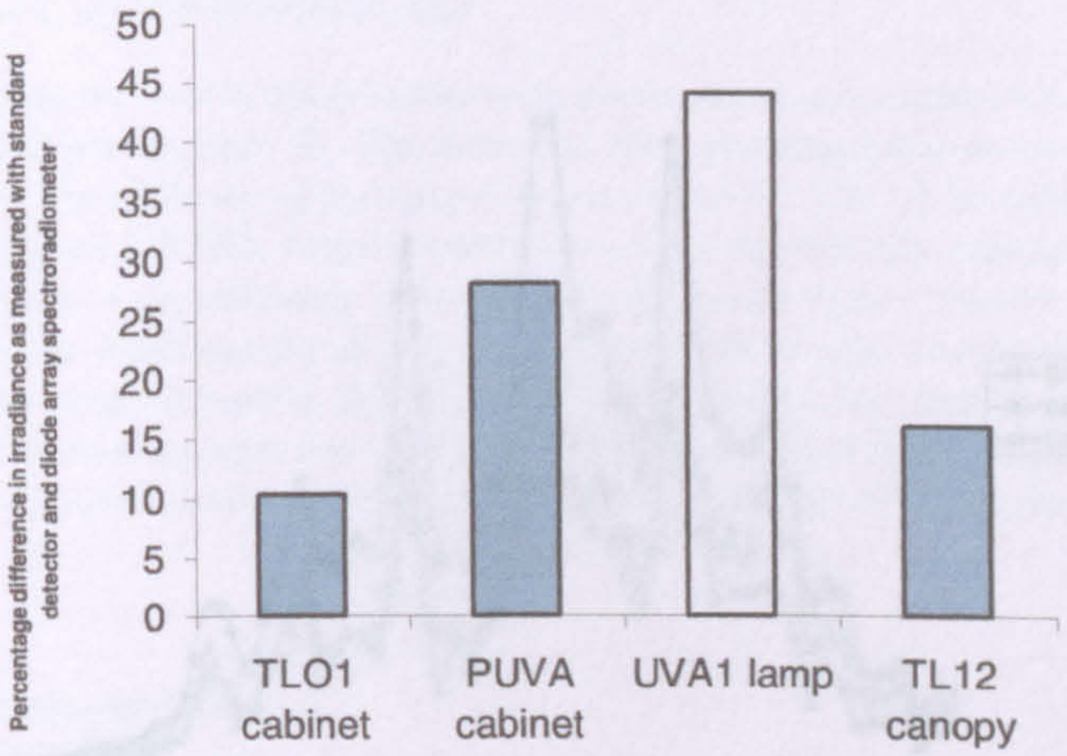

Figure 4. Graph to show the differences in measured irradiances when comparing manufacturer calibrated Sola Scope with IL1400 radiometer and, in the case of the UVA1 lamp, the Bentham spectroradiometer. TLO1 and TL12 values from the integrated irradiance 280–315 nm. PUVA and UVA1 from integrated irradiance 315–400 nm.

3.2. Stray light

The stray light levels with both instruments were significant, as was expected. The method of correcting stray light with the orange filter reduced the stray light significantly. Table 2 shows the stray light ratios if the signal at 250 nm (no irradiance, Schott 1993) is compared with that at 430 nm (maximum irradiance). The levels are significantly reduced when the Sola Scope's stray light compensation method is used and when the calibration is applied to the Ocean Optics' raw signal.

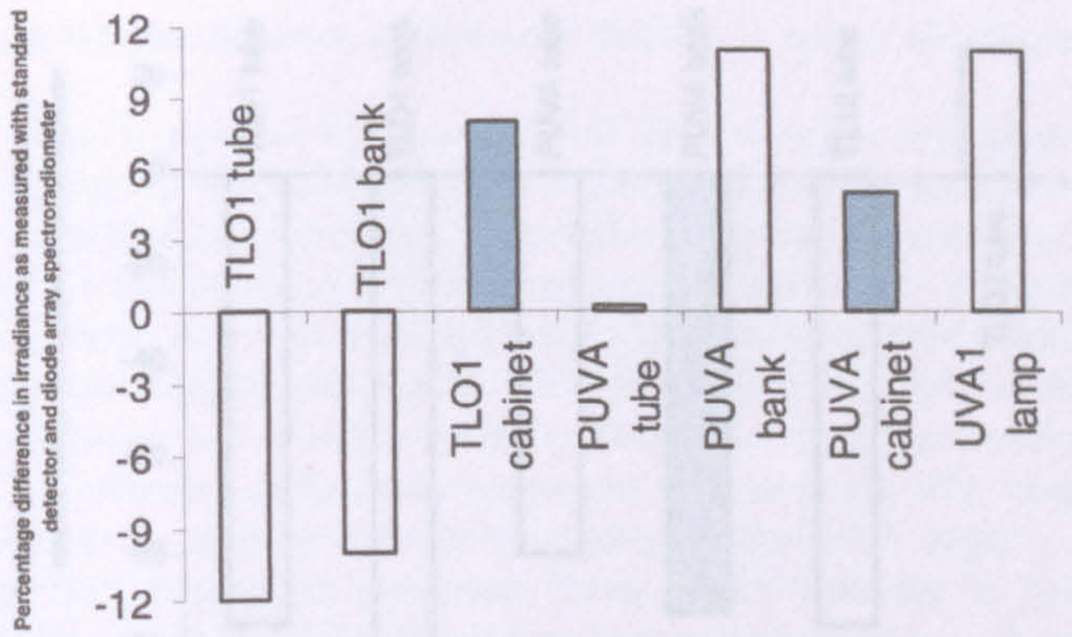

Figure 5. Graph to show the differences in measured irradiances when comparing custom calibrated Sola Scope with Bentham spectroradiometer and, in the case of the cabinets, an IL1400 radiometer. TLO1 values from integrated irradiance 280–315 nm. PUVA and UVA1 from integrated irradiance 315–400 nm.

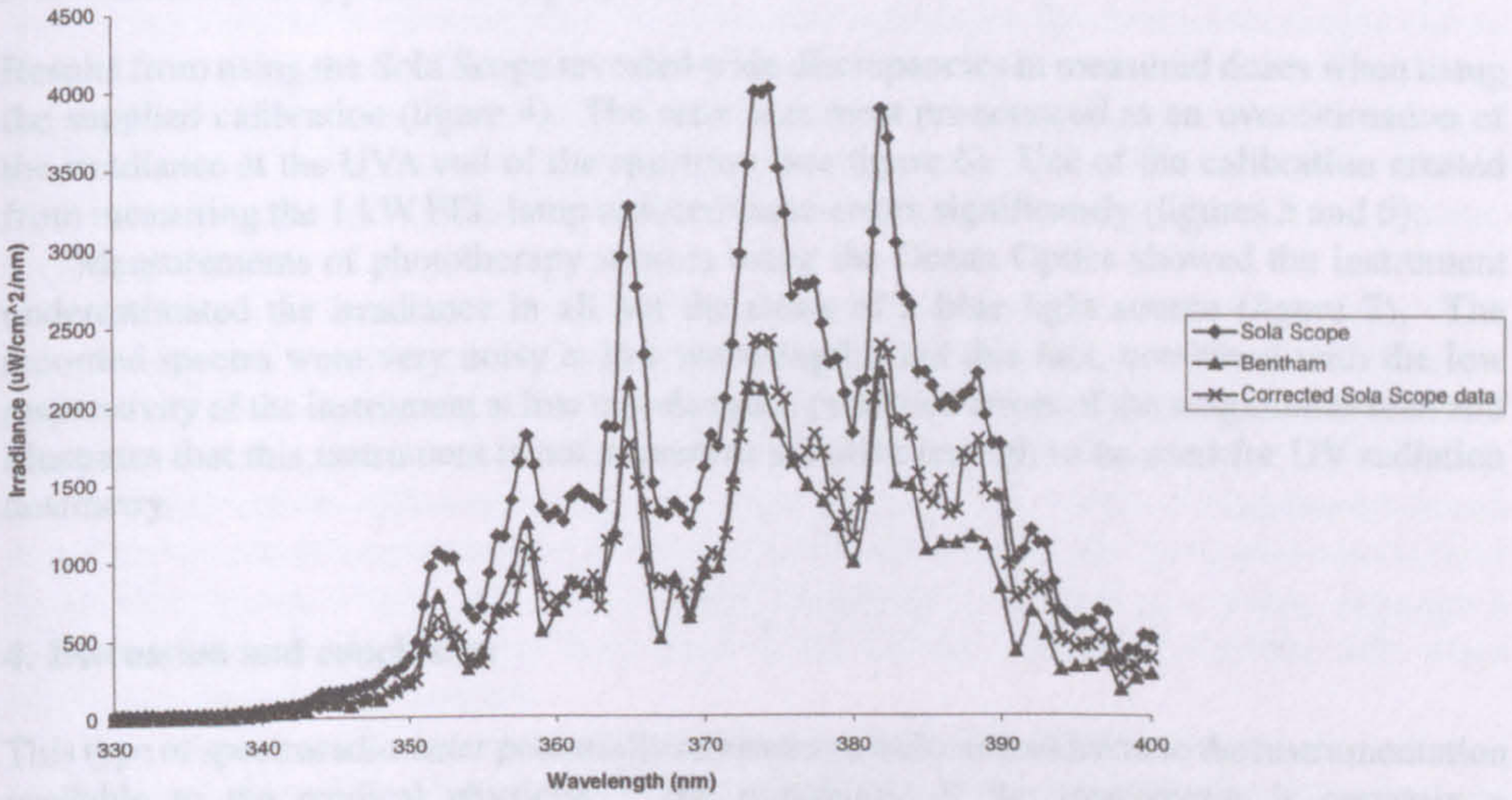

Figure 6. Measurement of a high dose UVA1 source which illustrates the discrepancy that was seen to exist with the Sola Scope's supplied calibration.

3.3. Angular response

The f_2 values for the instruments were both found to be within acceptable limits. For the Sola Scope the value was 5.1% in the plane parallel to its grating and 6.7% in the plane perpendicular to its grating (±60°). This provides an overall f_2 value of 5.9% (±60°). For the Ocean Optics the value was 7.8% (±60°). The cosine responses can also be represented as a polar plot (figure 3).

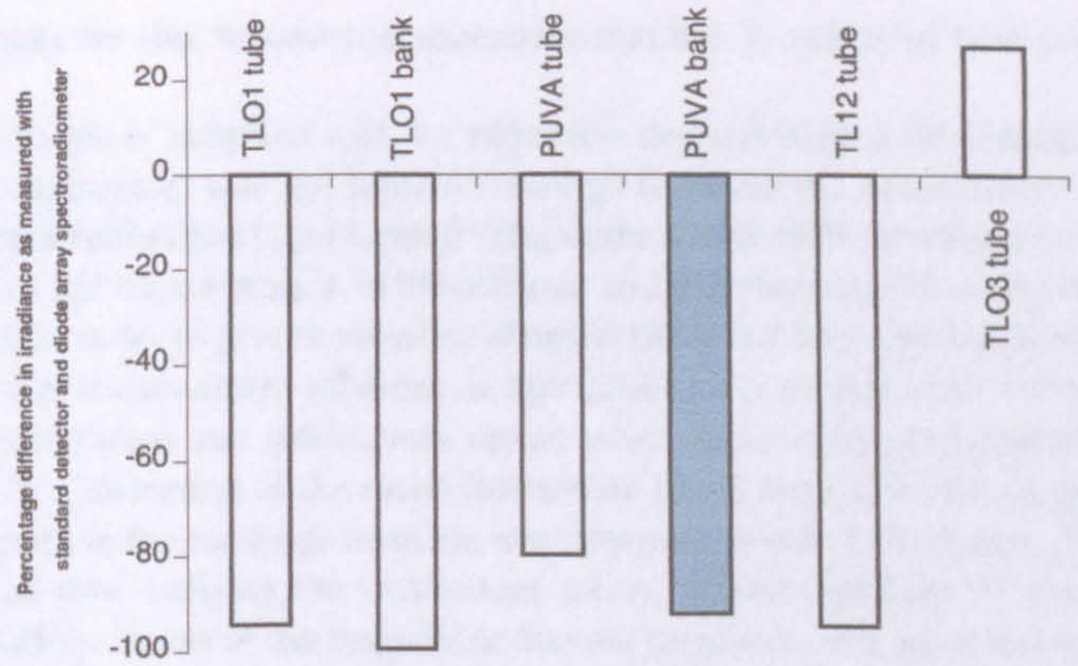

Figure 7. Graph to show the differences in measured irradiances when comparing calibrated Ocean Optics with Bentham spectroradiometer and, in the case of the PUVA bank, an IL1400 radiometer. TLO1 and TL12 values from the integrated irradiance 280–315 nm. PUVA from the integrated irradiance 315–400 nm. TLO3 from the integrated irradiance 400–500 nm.

3.4. Measurement of phototherapy sources

Results from using the Sola Scope revealed wide discrepancies in measured doses when using the supplied calibration (figure 4). The error was most pronounced as an overestimation of the irradiance at the UVA end of the spectrum (see figure 6). Use of the calibration created from measuring the 1 kW FEL lamp reduced these errors significantly (figures 5 and 6).

Measurements of phototherapy sources using the Ocean Optics showed the instrument underestimated the irradiance in all but the cases of a blue light source (figure 7). The recorded spectra were very noisy at low wavelengths and this fact, combined with the low responsivity of the instrument at low wavelengths, produced errors of the magnitudes seen and illustrates that this instrument is not at present sensitive enough to be used for UV radiation dosimetry.

4. Discussion and conclusion

This type of spectroradiometer potentially represents a welcome addition to the instrumentation available to the medical physicist. The portability of the instruments is certainly a very attractive quality and the relative speed and ease of acquiring spectral data is also desirable. However, the potential for inaccuracies in dosimetry has been shown to be significant.

One major issue encountered when calibrating both the instruments was the sensitivity of the detector arrays. Neither instrument proved to have sufficient sensitivity to detect the transfer standards usually employed in the department (see section 3.4). CIE guidelines (1984) recommend that detectors are calibrated against sources with a known spectral intensity and distribution that is similar to or the same as the source to be measured. Thus, the 1 kW FEL lamp employed was not ideal for UVB measurements but the instruments were not sufficiently sensitive to allow the use of a deuterium lamp. The deuterium discharge lamp is also a good approximation of a point source, and would normally be used for measuring the cosine response of any radiometer (Pye and Martin 2000). A xenon arc lamp was a second choice for

this measurement but did, however, demonstrate that the f_2 values of both instruments were acceptable.

The Sola Scope is supplied with a calibration derived from a deuterium source but we found that the instrument was not sensitive enough to detect the output from such a lamp. It transpires that the calibration is performed without the cosine diffuser attached to the sensor and a convolution of the transmittance of the diffuser and the responsivity of the detector array is then performed in order to give the final calibration (Ridyard 2002, personal communication). It is possible that uncertainties inherent in this calibration method lead to the error seen in the supplied calibration and subsequent errors when measuring phototherapy sources (see figures 5 and 7). Calibration of the intact instrument using the 1 kW FEL lamp was sufficient to reduce the error in the readings from the instrument to within 12% (figure 5). A calibration method such as this, keeping the instrument intact, would certainly be necessary for any clinical application. Errors of the magnitude that the supplied calibration was producing could certainly lead to patients receiving the wrong dose.

The UV responsivity of the Ocean Optics meant that even using the 1 kW calibration source, recorded spectra were similar to the noise inherent in the instrument. This meant that all the phototherapy sources measured were too low in intensity to give a discernible spectral output and it was only with a largely visible source that the signal was discernible (TLO3). This occurred despite the instrument supposedly being optimized for UV and visible wavelengths. This instrument could have potential in the clinical environment if its quantum efficiency in the UV were increased substantially. The calibration method for this instrument should also be revised. Very few light sources, and certainly not phototherapy sources, match the black body emission spectral profile. Convolution of some calibration source to this emission spectrum, based on colour temperature immediately introduces error into the calibration. The method that was used with the 1 kW FEL lamp would certainly be more satisfactory if the sensitivity issue is addressed.

The stray light levels in measurements from these instruments were high, as expected. It has been shown, however, that it is possible to compensate for the stray light by one of the two methods. An orange glass filter can be used to find the stray light profile for any source being measured and the 'profile' then subtracted from any final spectrum. Alternatively the stray light can be calibrated by including stray light in any spectrum of a calibration source and, therefore, including stray light in the sensitivity factor (SF_λ). The first method is the most favourable because it takes into account different spectral profiles of any source, although it requires two scans of any source to be made which can have potential exposure risks when measuring phototherapy sources.

The Sola Scope instrument currently shows significant potential for use in a clinical environment. The calibration supplied by the manufacturer was unsatisfactory but this could be improved using a high output source and stray light correction. With these modifications in place the errors in measuring phototherapy sources were calculated as being up to 12%, in line with errors inherent in filtered radiometer readings.

The Ocean Optics device should have its sensitivity increased and its calibration protocol re-written before it should be considered for phototherapy dosimetry.

Although there is potential benefit associated with this type of instrument, caution should be advised in its use within a clinical environment. Calibration issues surrounding this type of instrument have not yet been adequately addressed by manufacturers to advocate the replacement of the filtered radiometer in the photomedicine clinic with a device such as this. There would be particular concern over the use of a device such as this by non-specialist staff since errors can be considerable. An erroneous reading of the magnitudes reported in this paper could easily lead to a patient being burned.

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CASE REPORT

Clustered outbreak of skin and eye complaints among catering staff

Hannah Oliver[1,2], Harry Moseley[1], James Ferguson[1] and Angela Forsyth[3]

Abstract In August 2002, kitchen staff at a hotel in Central Scotland experienced skin and eye problems believed to be related to their working environment. Of a total of 20 staff, eight cooks reported problems with a painful red skin affecting the face, eyelids, side and front of neck as well as burning, gritty eyes. Five of the affected individuals were clinically assessed in April 2003. The overall clinical impression was of conjunctivitis and sunburn-like erythema. Examination of the data sheets of all cleaning agents and sprays used within the kitchen pointed against an environmental phototoxin. The kitchen area was inspected and two electric fly killers positioned on the ceiling and sidewalls were found to be incorrectly fitted with UVC tubes. The output of these tubes was spectroradiometrically assessed. The recommended unprotected skin and eye exposure limit was reached in 14 s at a distance of 30 cm from the tubes. An exposure of about 60 s would be sufficient to induce minimal erythema in someone of skin type I/II. These results demonstrate the importance of exposure to ultraviolet radiation as a possible cause of facial erythema and conjunctivitis, no matter how unlikely this may seem. It is recommended that there should be increased awareness of the need to fit the correct type of lamps to electric fly killers and other devices that incorporate UV lamps.

Key words Catering; electric fly killers; erythema; occupational; photokeratitis; sunburn; UVC.

Introduction

Work-related ocular damage is not uncommon [1]. One survey of patients attending an eye casualty unit in Scotland found that 21.7% of the cases were work-related [2]. Common eye injuries are due to chemical burns or foreign objects in the eye [3]. Two cases in the literature report eye problems due to incorrectly used UV sources in the workplace: a UVB source in one case [4] and a UVC source in another case [5]. UVC irradiation from welding equipment has caused or exacerbated skin conditions in three reported cases [6–8].

Occupational exposure to irritants can also cause skin disease. Gawkrodger *et al.* [9] reported the common occurrence of hand dermatitis in cleaners and kitchen workers in hospitals. Lammintausta *et al.* [10] found that 1% of hospital workers had hand dermatitis. This figure included, most commonly, cleaners, kitchen workers and nurses.

'Wet' occupations can increase the risk factor for developing hand eczema [11] and many cleaning products contain irritants and contact allergens [12,13]. Domestic and occupational products commonly contain fragrances, many of which are known to provoke contact allergy dermatitis [14]. Rarely, foodstuffs can cause allergic contact dermatitis [15–17] but as in the cases of irritant or contact dermatitis due to cleaning products, it is the hands that are most commonly affected.

A red face can have various explanations. Flushing is a common cause for a transiently red face [18]. Estimated figures suggest that as much as 10% of the general population suffer from rosacea that causes a characteristically reddened face and can increase the frequency of flushing. Patients with rosacea have also reported affected eyes, including dryness and chronic conjunctivitis [19]. The reddened face of seborrhoeic dermatitis may also involve secondary conjunctivitis, but the estimated occurrence of this dermatosis in the general population is only 1–3% [20]. Atopic dermatitis can be another cause of a red face, thought to affect 20% of the population, and the hands are commonly involved [21]. The face is also a common site for contact or photocontact dermatitis to manifest itself. Allergens may be airborne or in direct contact with patients' skin. Airborne allergens can also cause conjunctivitis [22].

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Table 1. Summary of presenting patients' symptoms

Patient	Age	Sex	Skin type	Shift worked	Marked tanning or erythema		Sore eyes	Precautions taken	Medical care sought	Days of work lost
					Face	Hands				
1	29	M	3	8–9 h	✓		✓	Ski goggles	GP	None
2	19	M	2	8 h	✓	✓	✓	None	GP	None
3	34	M	4	8 h shift split by 2.5 h	✓			None	GP	None
4	34	F	1	8 h shifts	✓		✓	Ski goggles	Attended casualty on one occasion	None
5	44	M	3	7.5 h painting the kitchen ceiling on one occasion	✓	✓	✓	None	Optician	5

In August 2002, kitchen staff at a hotel in central Scotland experienced skin and eye problems that they believed to be related to their working environment. Symptoms included reddened, peeling skin on the face and hands and burning 'gritty' eyes. This prompted the company's occupational health department to instigate an investigation into the cause of this outbreak. Occupational health contacted the Dermatology department at the local hospital and requested that the workplace be examined. Following the inspection, a request was made to further examine the kitchen in order to make radiometric measurements. The results of the investigation are presented in the current paper.

Patients and methods

Clinical cases

Out of 20 permanent kitchen staff, eight were reportedly affected. In April 2003, four of these were clinically evaluated at their workplace (patients 1–4). At the time of examination, all presented with erythema and some peeling on their faces. The skin on photoexposed sites was clearly pigmented. There was minimal involvement of the arms, hands and ears. Patients 1–3 also had conjunctivitis at the time of examination.

Patients 1 and 4 described the skin sensation as being very like sunburn. All except patient 3 complained of stinging, burning or 'gritty' eyes. The staff reported that their skin became red and sore in the evening following a shift at work. Peeling developed 1 day later. Symptoms always subsided within a day or two if they were not at work. The members of staff had all begun to suffer from October 2002 onwards.

Patient 5 presented with no symptoms. He had suffered only one episode of skin and eye trouble the morning after he had painted the kitchen during one night in November 2003. All lights were on in the kitchen and he had painted the ceiling using a long armed roller. Three hours after finishing the painting, he reported painful, swollen and weeping eyes, reddened and peeling skin. The symptoms cleared over a 5-day period off work. He has not had any recurrence of the symptoms since.

The patients' symptoms are summarized in Table 1. The skin type (Table 2) of the individual did not seem to affect the severity of their symptoms. There was no history of atopy, drug ingestion, family involvement or excessive consumption [23] of psoralens (e.g. celery or parsnips) in any of the patients examined. None had a past history of contact allergy or were taking photoactive medication.

Table 2. Fitzpatrick skin types [39]

Skin type	Colour	Reaction to sun
Type I	Very fair, blond or red hair, freckles, blue eyes	Always burns, never tans
Type II	Fair skin, blond or red hair, freckles, blue or green eyes	Burns easily, tans with difficulty
Type III	Fair to medium skin tone	Burns moderately, tans gradually
Type IV	Medium skin tone	Rarely burns, always tans well
Type V	Olive or dark skin tone	Very rarely burns, tans very easily
Type VI	Deeply pigmented	Never burns

Clinical impression

The overall clinical impression was conjunctivitis and sunburn-like erythema. It would be extremely unlikely that 24% of a workforce would have independently and simultaneously developed a dermatosis such as rosacea or seborrhoeic dermatitis. Eczema would not account for the ocular involvement. Given the prevalence of occupational skin disorders in kitchen staff, an irritant in the kitchen environment was suspected.

Interestingly, kitchen staff working split shifts (10 am–2 pm and 5 pm–10 pm) reported no symptoms or lesser effects than their colleagues working 8-h stretches. This

implied that the threshold dose for the irritant was only exceeded after 4 h.

The involvement of the face, hands and eyes might have suggested an airborne irritant rather than one that required physical contact. Nevertheless, cleaning products were suspected, because irritants can be transferred from hands to face and eyes in affected individuals. However, examination of the data sheets of all cleaning agents and sprays used within the kitchen pointed against an environmental phototoxin.

Hotel management had provided the staff with ski goggles to wear in order to protect their eyes. Only patients 1 and 4 chose to wear the goggles. They found that their skin involvement continued, although the eyes and area photoprotected by the goggles was no longer affected. This evidence, along with the marked cut off of erythema on photoprotected skin suggested that there might be a UV source in the kitchen. Thus, the decision was made to examine the light sources in the kitchen for hazardous levels of UV.

Kitchen evaluation

The hotel had several kitchens, but the affected individuals all worked in one area. This area was inspected and hazard measurements were made using an International Light Sλ weighted radiometer. This detector is a filtered photodiode and gives a weighted irradiance (W/m^2) value indicating the hazard associated with the measured source. Spectral irradiance measurements were also taken from several light sources in the kitchen using a single grating, diode array Sola Scope 2000 meter with calibration traceable to the National Physical Laboratory (NPL, Teddington, UK) [24].

Results

The on site survey using the Sola Scope 2000 meter revealed that incandescent lamps positioned on the food counter (to keep food hot) were found to emit some UV, but the Sλ meter readings confirmed that this was not enough to be hazardous to health. Similarly, overhead fluorescent lights were found to emit minimal UV. There were also electric fly killers placed around the kitchen. Two of these units (Rentokil) contained clear fluorescent tubes with no phosphor coating in evidence. The Sola Scope 2000 meter proved to have too little sensitivity at low wavelengths to detect any hazardous UV, but the Sλ radiometer readings at 20 cm from the unit suggested that there was a hazardous level of UV emitted from these tubes ($1\ W/m^2$).

There was a label on the units that stated that the tubes had been cleaned and replaced in July 2002. This date corresponds closely to the start of the skin and eye complaints. The tubes themselves were labelled 'UVC' and 'Dangerous for skin and eyes' on the outside of the glass envelope. UVC-induced erythema and photokeratitis account for all the symptoms reported by the hotel staff [25]. Patient 5 suffered the worst episode of photokeratitis because he was looking upwards in the direction of the UVC sources while he was painting the kitchen ceiling.

One of the tubes was removed from one of the fly killers and taken to the United Kingdom Accreditation Service (who provide independent proficiency inspection and certification for calibration and testing laboratories) accredited photo laboratory at Ninewells Hospital, Dundee for accurate measurement of the spectral irradiance from the source. Measurements were made at a distance of 30 cm using a Bentham DM150 double grating spectroradiometer. This instrument has a cooled photomultiplier tube ($-20\,°C \pm 1°$) and its calibration is traceable to NPL. The tubes were found to emit strongly in the UVC region (100–280 nm) (Figure 1). Total irradiance from the tubes (200–600 nm) was found to be $4.6\ W/m^2$. Guidance on maximum occupational exposure levels to unprotected skin and eyes has been published by the International Radiation Protection

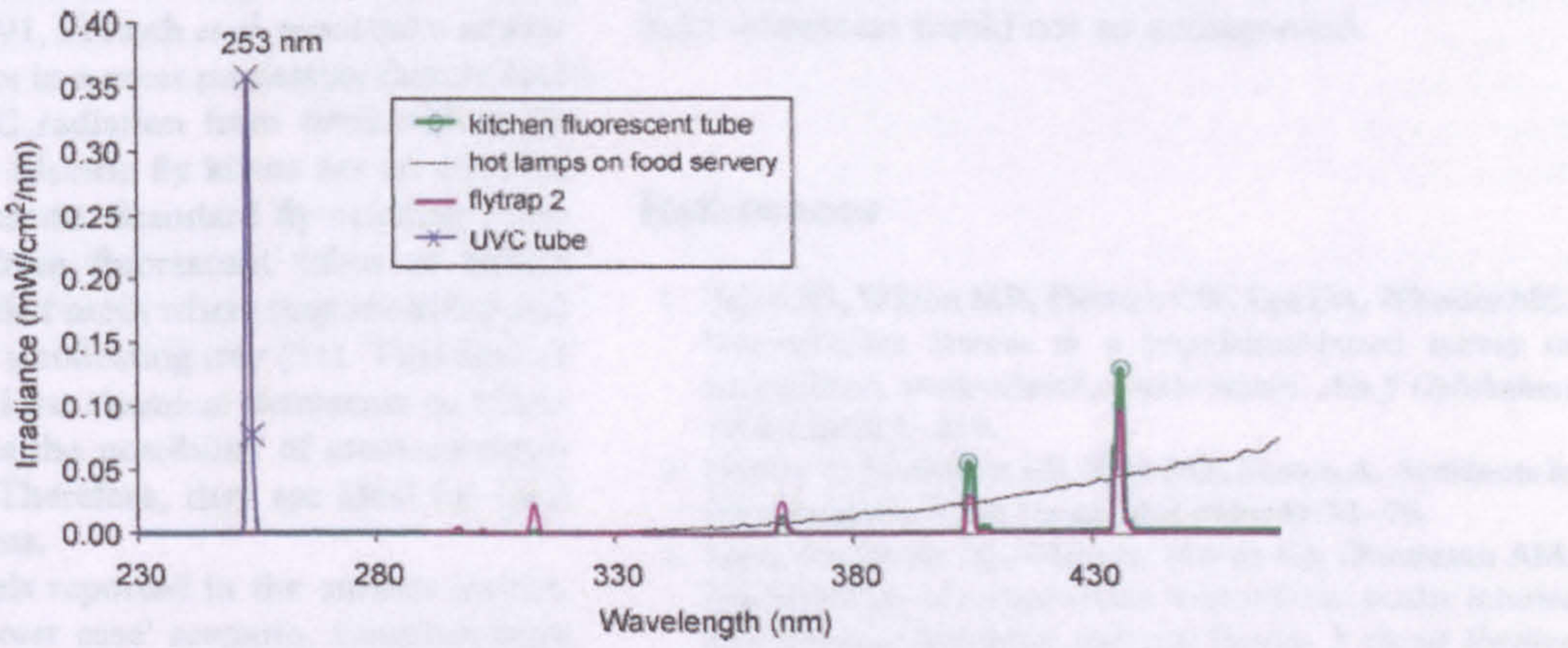

Figure 1. Spectra of the light sources found in the kitchen. The intense UVC radiation from the UVC tube can clearly be seen.

Association [26] and is used by the Health & Safety Executive in the UK. Application of these guidelines to the spectral output from the lamp indicates that the recommended exposure limit would be exceeded only after 14 s. This calculation involves the use of the so-called Sλ weighting function that gave an effective irradiance of 2.2 W/m^2. The occupational exposure limit is an Sλ weighted effective dose of 30 J/m^2. Since 1 W = 1 J/s, the time to reach the exposure limit is found by dividing the exposure limit by the effective irradiance from the lamp. The same weighting function can be used to calculate the time to the threshold dose for photokeratitis. This threshold is between 50 and 100 J/m^2 effective dose [27]. This dose would have been reached in 23–46 s.

Erythemal weighting [28] of the UVC tube spectra revealed that the erythemal effective irradiance was 4.5 W/m^2. This weighting function takes account of the relative effectiveness of different wavelengths to induce erythema. Midday Southern European summer sun, by contrast, has an erythemally effective irradiance of 0.27 W/m^2 [29]. The UVC tube would thus deliver one standard erythema dose (100 J/m^2) [30] in 22 s. For comparison, it would take >200 s to receive a similar dose at a distance of 30 cm from a narrow band UVB (TL01) unit consisting of eight tubes, such as one might find in a phototherapy unit for treatment of psoriasis.

The spectra obtained from the light sources in the kitchen are shown in Figure 1. The relative intensity of the UVC tube is clear to see. This figure also shows the spectrum of the correct type of tube to fit in electric fly killers.

Given the results obtained, it was recommended that the UVC tubes were removed. This was done and the employees' problems resolved very soon afterwards.

Discussion

Although cases of occupational UVC irradiation are rare [6–8], episodes of accidental exposure have been reported before. In 1991, Forsyth *et al.* reported a similar incident where workers in a meat processing factory had been exposed to UVC radiation from similar Rentokil electric fly killers [5]. Electric fly killers are an effective method of trapping insects. Standard fly catching tubes use UVA radiation from fluorescent tubes to attract insects onto an electrified mesh where they are killed and their bodies drop into a collecting tray [31]. This kind of trap removes the need for chemical deterrents or killers and thus also removes the possibility of cross-contamination of foodstuffs. Therefore, they are ideal for (and widely used in) kitchens.

The irradiance levels reported in the current investigation represent a 'worst case' scenario. Catering work involves moving about the workplace and generally looking down at food that is being prepared. An accurate measurement of the actual dose that the staff received could only have been achieved by attaching dosimeters to the staff uniform. Nevertheless, occupational exposure limits were obviously exceeded during a working day as the limits are set so as to avoid symptoms of exposure. These devices were mounted overhead and therefore the heads, faces and necks of the staff were receiving the majority of the radiation. This explains why there was minimal involvement of the arms and hands. Hats are also worn in the kitchen, which explains why the ears were unaffected in most of the individuals.

The UVC tubes were fitted in July 2002 and the authors did not inspect the premises and identify the problem until late April 2003. Therefore, staff had been exposed to this radiation for about 9 months before the tubes were identified. The effects of long-term UVC exposure in humans are not known. UVC radiation is known to be mutagenic [32,33] and causes erythema in much the same manner as excessive UVB irradiation does [34]. While UVC photons are more energetic and therefore more damaging than longer wavelength UVB and UVA photons, they do not penetrate tissue as deeply so that undesirable effects are confined to the outer tissue layers [35]. For example, in the eye, UVC radiation is absorbed by the cornea and is not, therefore, transmitted to the retina [36].

This incident highlights the confusion that can occur resulting in incorrect tubes being fitted to electric flytraps. This type of tube is designed for air, water or surface sterilisation [37,38] and should not be used in fly killers. We suggest that the UVC tubes are labelled more clearly and that manufacturers obtain more details as to the intended application before supplying tubes of this type. We would also welcome a decision by manufacturers to make UVC tube fittings differently from other fluorescent tubes so that it would become impossible for end-users to fit this type of tube in error. Potential users and health professionals should also be educated as to the potential adverse affects of this type of UV tube so that these symptoms would not go undiagnosed.

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Appendix 2

Presentations

Diode array spectroradiometers: An Evaluation of Two Instruments in a Medical Context, *UV Network meeting*, Halkidiki, Greece, October 2002

The Potentials and Pitfalls of Using Diode Array Devices to Measure Light Sources, *Scottish Skin Biology Club*, Edinburgh, November 2002

Determining the reaction of photosensitive patients to polychromatic light sources, *Medical Physics Journal Club*, Ninewells Hospital, September 2003

Too many cooks with red faces, *Scottish Dermatological Society*, Dundee, October 2003

Predicting the reaction of photosensitive patients to polychromatic light sources: A mathematical method based on monochromator testing. *European Society for Photobiology Conference*, Vienna, September 2003

Transmittance of sunscreen products from 600 to 800 nm. Poster presentation. *European Society for Photobiology Conference*, Vienna September 2003

had either closed or dispensed with their sunbeds. Hence, 11 premises were visited for the first time, only 4 of which were known to the council and a further 7 that were identified by telephone enquiry.

Dundee

There are 23 premises in Dundee with 86 beds (43 beds and 43 booths). Three of these are local authority sports centres (gyms), one of which has 6 sunbeds and the others which offer just one.

Spectral Measurements

Calibration of the instrument

Separate calibrations were made for fluorescent UVA tubes and for metal halide lamps, see figure 5.13. The mean calibration factor for UVA fluorescent tubes was 1.11, indicating an underestimation of the irradiance from the instrument if its in built calibration were used. In particular, the peak at 312 nm had to be corrected by a factor of 3.

Conversely, with the metal halide lamp, the average correction factor was 0.4 indicating that the Sola Scope overestimated the irradiance from this lamp using its in built calibration factor. The relative differences in these calibration factors are likely to be due to the different spectral distributions of these lamps, creating different stray light profiles, which are then calibrated out.