AN INVESTIGATION INTO THE ULTRAVIOLET RADIATION EXPOSURE OF CHILDREN AND ADOLESCENTS IN DURBAN

by
Caradee Yael Guy
B. Soc. Sc. (Hons)

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School of Life and Environmental Sciences
University of Natal
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ABSTRACT

Stratospheric ozone plays an important role in absorbing ultraviolet radiation. The well-known depletion of the ozone layer has raised several concerns in terms of an expected increase in surface ultraviolet radiation. South Africa, situated in the southern mid-latitude regions, has experienced a general downward trend in total column ozone since 1979. As a result of this negative trend in total column ozone, the ultraviolet flux at the earth's surface is expected to increase. Excessive exposure to ultraviolet radiation is known to have acute and chronic effects on human health, including erythema and skin cancer.

Numerous studies have acknowledged a relationship between childhood ultraviolet radiation exposure and the risk of contracting skin cancer, namely malignant melanoma, during adulthood. The aim of this study is to investigate the ultraviolet radiation dose and exposure of children and adolescents in Durban, South Africa. Polysulphone film badges were used to quantify the daily erythemal ultraviolet radiation dose of 30 individuals of varying ages and skin types, engaged in different activities, over a one-week period during summer. The results highlight the diversity of childrens' and adolescents' behavioural patterns, with behaviour being found to play an important role in determining an individual's ultraviolet radiation dose.

The mean daily erythemal ultraviolet radiation dose of the children and adolescents was 1.03 MED units with a median of 0.57 MED units and a 95% range of 0.22 - 7.22 MED units. The most striking finding was that the median value was below the critical value of 1 MED unit. An explanation for the unexpectedly low erythemal ultraviolet radiation doses recorded in this study was sought in the prevailing climatic conditions. Ambient erythemal ultraviolet radiation levels recorded during the study period were high, ranging between 20.57 - 30.60 MED units. However, high temperatures (>27°C), coupled with high humidity values, may have encouraged the children and adolescents to avoid direct sunlight and find shade while outdoors.

The daily erythemal ultraviolet radiation doses of the children and adolescents were also compared to the ambient erythemal ultraviolet radiation levels received on a horizontal surface by a YES UVB-1 pyranometer located at the University of Natal (Durban). Children and adolescents in Durban received approximately 4.58% of the total daily ambient erythemal ultraviolet radiation incident upon a horizontal surface. This was found to be similar to a study (5 - 6%) conducted by Diffey *et al.* (1996) in

England, as well as a study (4 - 8%) by Gies *et al.* (1998) in Brisbane, Australia. The personal ultraviolet radiation exposure journals of the children and adolescents were used to determine the timing of exposures, duration of exposures and nature of outdoor activities and these were then related to their daily ultraviolet radiation doses.

Of all the factors considered, the nature of an individual's activity was found to have the strongest influence in determining their ultraviolet radiation dose. An activity model was derived in order to investigate the effect of activity on ultraviolet radiation dose, where three activity factors, namely swimming, walking and tennis, were calculated for a South African context and compared with those from previous international studies. It was found that the activity factors derived in this study were similar to Holman *et al.* (1983) and Herlihy *et al.* (1994) and may be used in an activity model to estimate individual erythemal ultraviolet radiation dose for a particular activity. The value of this innovative activity model lies in its ability to predict individual ultraviolet radiation dose and this may help to emphasise the importance of responsible outdoor behaviour.

A mannequin was used to quantify the anatomical distribution of erythemal ultraviolet radiation under clear sky and overcast conditions. It was found that the vertex of the head and shoulders received the highest erythemal ultraviolet radiation doses under both conditions. This was then related to the erythemal ultraviolet radiation doses of the children and adolescents as recorded by the polysulphone film badges in order to identify anatomic sites susceptible to high erythemal ultraviolet radiation doses. Behaviour alternatives and ultraviolet radiation protective mechanisms were discussed and recommendations made for children and adolescents residing in Durban.

PREFACE

The work described in this dissertation was carried out in the School of Life and Environmental Sciences, University of Natal (Durban), between November 2000 and December 2001, under the supervision of Professors R.D. Diab and B.S. Martincigh, in fulfilment of the academic requirements for the degree of Master of Social Science.

This study represents original work undertaken by the author and has not been submitted in any other form to another university. Where use has been made of the work of others it has been duly acknowledged in the text.

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GLOSSARY

Absorption unit (A): Unit used to measure the change in absorption of polysulphone film that can then be related to its ultraviolet radiation dose.

Action spectrum: The actual rate of damage to an organism producing an observable effect as a function of wavelength and depending on the sensitivity of the receptor.

Ambient ultraviolet radiation: Solar ultraviolet radiation incident upon the surface of the earth.

Anatomic site: One particular physiological part of the body, for example the chin, forearm or calf.

Anatomical distribution: The distribution of a particular effect for all anatomic sites.

Basal cell carcinoma (BCC): A type of non-melanoma skin cancer that arises from basal cells located in the lower epidermis of the skin and visible in its initial stages as a small, hard and painless superficial nodule that becomes raised and pearly-edged with an ulcerous crust.

Dark-skinned individuals: Individuals with a dark skin colour who never burn and tan profusely.

Dose: The total energy of ultraviolet radiation absorbed by unit mass of material, i.e. of living tissue such as the skin.

Erythema: An acute effect on the skin following excessive exposure to ultraviolet radiation where the skin becomes red due to an increase in the blood content of the epidermal and dermal cells caused by the dilation of small blood vessels in the skin's dermis. Also commonly known as sunburn.

Erythemal ultraviolet radiation (EUV): It refers to the ultraviolet irradiance between 280 - 315 nm which is then weighted by the Diffey erythemal action

spectrum, also known as the CIE action spectrum, to get biologically weighted irradiance.

Exposure: The act of being exposed or subjected to the influence of solar ultraviolet radiation.

Hawthorne effect: A distortion of research results caused by the response of subjects to the special attention they receive from researchers. The effect was first noticed in the Hawthorne plant of Western Electric where production increased as a consequence of management's demonstrated interest in such improvements.

Irradiance: The quotient of the radiant flux incident on an element of the earth's surface.

Keratinocytes: Components of the skin that are derived from a single germinative layer of basal cells in the skin and produce keratin, the fibrous protective proteins of the skin.

Light-skinned individuals: Individuals with a fair skin colour who burn easily and severely, tan little and usually peel.

Malignant melanoma skin cancer (MMSC): A type of skin cancer in which a malignant tumour arises from melanocytes, the pigment-producing cells of the skin, metastisises in size and, if untreated, may cause death.

Medium-skinned individuals: Individuals with a medium skin colour who burn minimally, tan easily and seldom burn.

Minimal erythemal dose (MED): The amount of ultraviolet radiation required to produce minimal erythema or perceptible redness of the skin. One MED unit is equivalent to 200 J m^{-2}. The number of MED units required to induce varying levels of erythema (minimal, painful and severe) is dependent on skin type.

Nevus: A group of darkly pigmented cells at or near the skin's surface that is commonly known as a mole. Nevi may be congenital (present from birth) or acquired (appearing in latter years). A benign nevus is harmless, however, a severely dysplastic nevus has been associated with malignant melanoma skin cancer and may therefore serve as a risk indicator for this type of skin cancer.

Non-melanoma skin cancer (NMSC): A collective term used to describe basal cell carcinoma and squamous cell carcinoma.

Photokeratitis: Also known as snowblindness, the ocular equivalent of sunburn that occurs after short term exposure to ultraviolet radiation and is characterised by a reddening of the eyeball, a gritty feeling of severe pain, tearing and twitching.

Polysulphone film (PSF): A polymer that was identified as a reliable means of measuring an individual's ultraviolet radiation dose since the dosimeter had a monotonic response as the ultraviolet radiation dose increased and the wavelength response of the dosimeter was similar to the erythemal action spectrum of human skin.

Risk: The likelihood and magnitude of a detrimental outcome as a result of a particular activity or event.

Skin type: The delineation of different types of human skin based on skin colour and skin reaction to solar ultraviolet radiation. For the purpose of this study, three skin types have been defined, i.e. light, medium and dark.

Solar retinopathy: An acute disease of the retina of the eye caused by intense exposure to ultraviolet radiation.

Squamous cell carcinoma (SCC): A type of non-melanoma skin cancer that begins in the squamous cells of the epidermis and originates as a small nodule that grows rapidly into a raised ulcer surrounded by a wide, elevated border.

Sunburn: See erythema.

Suntan: See tan.

Tan: A brownish colouring or darkening of the skin caused by the formation of the pigment melanin within the upper regions of the skin as a result of exposure to ultraviolet radiation.

Ultraviolet radiation: Solar ultraviolet radiation has wavelengths between 220 – 400 nm of the electromagnetic spectrum and consists of three bands, i.e. UVA, UVB and UVC.

UVA: Spectral region of the ultraviolet band lying between 315 - 400 nm.

UVB: Spectral region of the ultraviolet band lying between 280 - 315 nm.

UVC: Spectral region of the ultraviolet band lying between 220 - 280 nm.

Vertex: An anatomic site, commonly known as the crest of the head, which is often used as a reference point in ultraviolet radiation exposure studies that use mannequins.

Yankee Environmental Systems (YES) UVB-1 pyranometer: A variation of the Robertson-Berger meter that measures global solar ultraviolet radiation incident upon the earth's surface.

Chapter One
INTRODUCTION

1.1 Background to the study

Stratospheric ozone plays an important role in absorbing short wavelength solar ultraviolet radiation and reducing the amount of ultraviolet radiation received at the earth's surface. The well-known depletion of the ozone layer has raised several concerns with regard to an expected increase in surface ultraviolet radiation. While the downward trend in stratospheric ozone is assessed on the basis of observation supported by theory, a corresponding upward trend in surface ultraviolet radiation is not as easily detectable, since the ultraviolet band comprises a relatively small portion of the electromagnetic spectrum (Meloni *et al.*, 2000). However, various studies have observed the relationship between stratospheric ozone depletion and increased surface ultraviolet radiation, including Herman *et al.* (1996), Bodeker and Scourfield (1998) and Prause *et al.* (1999).

South Africa is situated in the mid-latitude region of the Southern Hemisphere. According to various studies it has experienced a general downward trend in total column ozone since 1979 (Diab *et al.*, 1992; Kalicharran *et al.*, 1993 and Bodeker and Scourfield, 1998). As a result of this negative trend in total column ozone, surface ultraviolet radiation levels are expected to increase. Overexposure to relatively high levels of surface ultraviolet radiation is known to have adverse impacts on biological systems. The effects of increased ultraviolet radiation on human health include photo-ageing of the skin, erythema, cataracts, immuno-suppression and skin cancer (Armstrong, 1994). Ultraviolet radiation has been shown to play a distinct aetiological role in the formation of non-melanoma skin cancer (NMSC) (Diffey and Saunders, 1995). It has been suggested that an increase in surface ultraviolet radiation may lead to a significant increase in the incidence of skin cancer (Henriksen *et al.*, 1990).

Numerous studies have noted a relationship between childhood ultraviolet radiation exposure and the development of skin cancer during adulthood (Lew and Rosenthal,

1988; Diffey *et al.*, 1996; Gies *et al.*, 1998; Moise *et al.*, 1999a; Moise *et al.*, 1999b, Kimlin and Parisi, 2000 and O'Riordan *et al.*, 2000). Overexposure to ultraviolet radiation before the age of 20 years is thought to increase this risk, particularly in terms of developing malignant melanoma skin cancer (MMSC) (Weinstock *et al.*, 1989; Moise *et al.*, 1999a). Cancer statistics between 1993 - 1995 for South Africa indicate that a total of 31 626 cases of skin cancer, including basal cell carcinoma (BCC), squamous cell carcinoma (SCC) and MMSC, were diagnosed in formal medical practices (CANSA, 2001). This is a relatively large number of cases when compared to formally diagnosed cases of lung cancer totalling 5601 during the same period (CANSA, 2001). Considering the hypothesis that childhood ultraviolet radiation exposure plays a significant role in increasing the risk of skin cancer, there is a need to quantify the ultraviolet radiation doses and exposure patterns of children and adolescents in South Africa in order to assess personal risk and determine preventative methods. This study will focus on young children and adolescents residing in the city of Durban.

1.2 Study area

The city of Durban is situated on the eastern coastline of South Africa in the province of KwaZulu-Natal (Figure 1.1). It is located in the subtropical belt of the Southern Hemisphere at approximately 32° 58′ South and 29° 52′ East. Durban is situated at a similar latitude to Brisbane in Queensland Australia, which is a region known for having one of the highest incidence rates of NMSC in the world (Scotto, 2001). A combination of relatively high ambient ultraviolet radiation levels and a favourable climate that promotes an outdoor lifestyle contributes towards the high occurrence of NMSC in Queensland (Scotto, 2001).

The city of Durban also has a favourable climate. Statistics for Durban obtained from the South African Weather Service for the years 1961 - 1990 state that average air temperatures range between 10° - 23°C during winter (June, July and August) and 20° - 28°C during summer (December, January and February) (SAWB, 1996). Relative humidity may exceed 83% during summer months. The average number of sunshine

hours per day for all days of the year is 6.4 hours (SAWB, 1996). Cloud cover ranges between an average of 4.4 - 6.6 octas during summer and 2.2 - 3.8 octas during winter (SAWB, 1996). The average number of days when rainfall is experienced in one year is approximately 130 (SAWB, 1996).

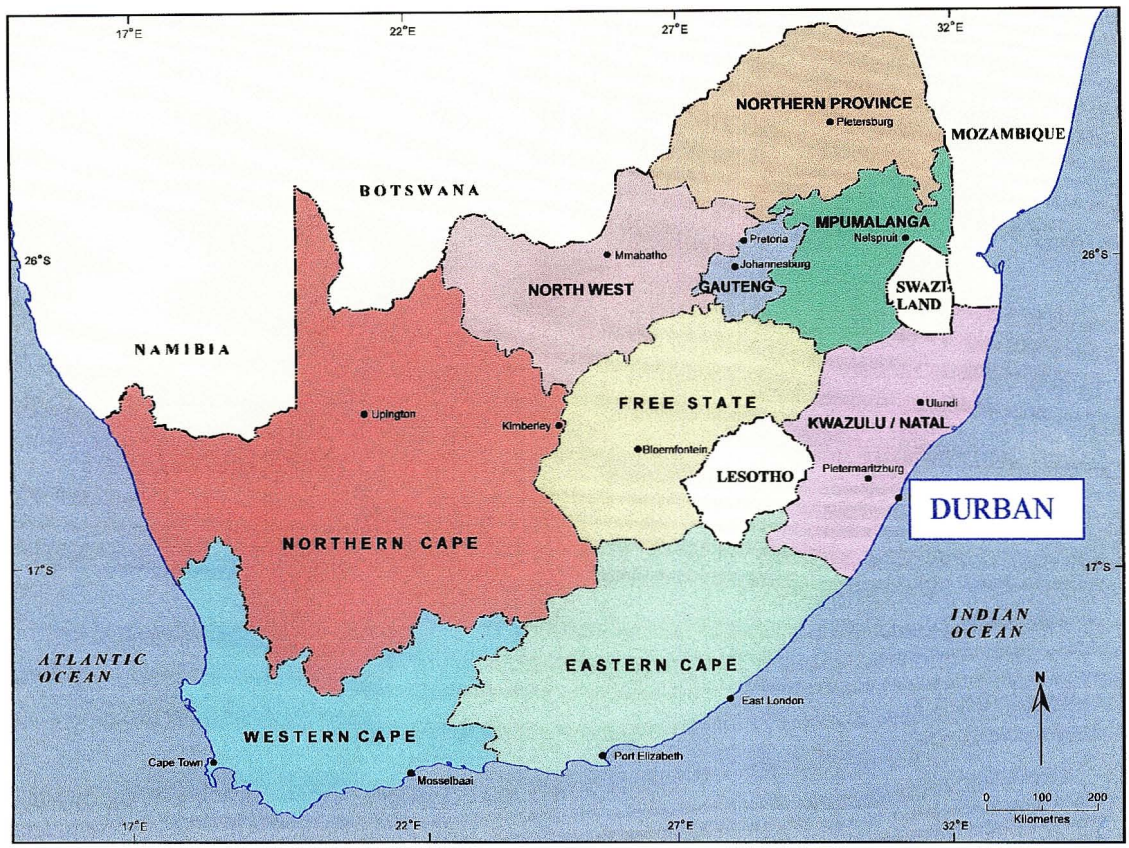


Figure 1.1: Map showing the Republic of South Africa and the city of Durban (Courtesy of: Mr Hem Hurrypursad, School of Life and Environmental Sciences, University of Natal, Durban)

Duigan (1995) states that there is evidence to suggest that Durban receives relatively high levels of ambient erythemal ultraviolet radiation (EUV), particularly during summer and that these levels are of significant proportions to raise concern. Compared with Cape Town and Pretoria, Durban received relatively lower levels of ambient EUV during the summer months of 1994 - 1998 (SAWS, 2001). This is likely on account of the influence of cloud cover. However, total daily ambient EUV levels for Durban typically range between 25 - 30 MED units, where 1 MED unit induces a minimal perceptible redness of the skin in light-skinned individuals (Guy, 2000).

Noon EUV burn times for light-skinned individuals may be approximately 10 minutes (Duigan *et al.*, 1995). Since Durban's climate is conducive to an outdoor lifestyle and promotes a 'beach culture', high ambient EUV levels are likely to lead to increased health risks associated with extended periods of ultraviolet radiation exposure.

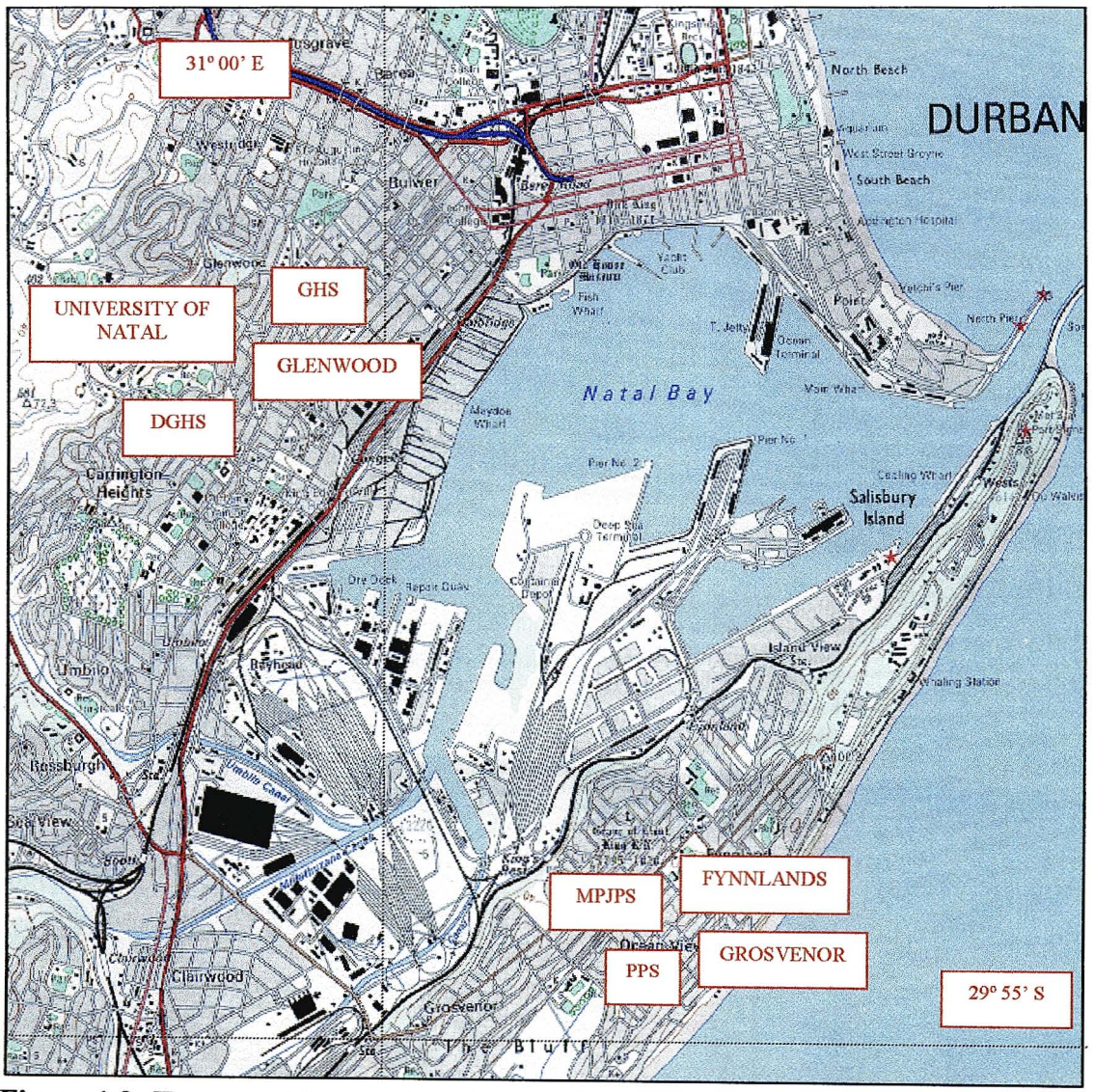


Figure 1.2: Topographic map showing the city of Durban, the University of Natal, Panda Pre - Primary School (PPS), Marlborough Park Junior Primary School (MPJPS), Durban Girls' High School (DGHS) and Glenwood High School (GHS) (Courtesy of: Mr Hem Hurrypursad, School of Life and Environmental Sciences, University of Natal, Durban)

The health risks associated with exposure to ultraviolet radiation may be assessed for an individual once their individual ultraviolet radiation dose is known. The children and adolescents observed in this study were all residents of Durban attending four local schools situated in three suburbs: Glenwood, Fynnlands and Grosvenor (Figure 1.2). All four schools lie within 8 km of the University of Natal (Durban). The suburbs are predominantly formal residential areas and have direct access to the city's main beaches along well-established roads.

1.3 Previous studies

A previous study undertaken by Guy (2000) assessed the human health risks associated with exposure to ultraviolet radiation in Durban, South Africa. It was calculated, through the application of a health risk assessment model and risk equations (Diffey, 1992), that the potential EUV dose of a child may be of significant proportions to induce minimal erythema on a daily basis. Moreover, a child may experience severe or painful erythema on days of lengthy exposure to ultraviolet radiation, particularly when ambient EUV levels are relatively high.

The application of the health risk assessment model had a number of drawbacks since it used ambient EUV measurements to calculate an individual's EUV dose. The study included an estimate of an individual's ultraviolet radiation exposure periods. A means of overcoming these shortfalls is the employment of polysulphone film badges (PSFBs) worn by living subjects who then document their ultraviolet radiation exposure periods in a personal journal.

Similar studies monitoring personal ultraviolet radiation exposure patterns have been done in other countries, however, it is believed that this is the first application of its kind in South Africa. Diffey *et al.* (1996) measured the ultraviolet radiation dose of children between the ages of 9 - 10 years and 14 - 15 years in three geographically distinct regions in England over a three month period during summer. Gies *et al.* (1998) assessed the ultraviolet radiation of primary school children in Brisbane, Toowoomba and MacKay (Australia) over a two week period using PSFBs. Moise *et*

al. (1999b) used PSFBs to measure the ultraviolet radiation exposure of infants and small children living in Townsville, Australia.

Holman *et al.* (1983) used PSFBs to investigate the proportions of ambient EUV received at several anatomic sites in 5 occupations and 9 outdoor recreation activities. Herlihy *et al.* (1994) quantified the ultraviolet radiation dose received during 6 different outdoor activities using similar badges in Tasmania. Gies *et al.* (1995) measured the ultraviolet radiation exposure of outdoor workers, physical education teachers, ground staff/gardeners and lifeguards using PSFBs on the Sunshine Coast, Australia. These studies have provided the background against which this study has been undertaken. In order to assess the risk of ultraviolet radiation exposure and to make recommendations for preventing these harmful effects for children and adolescents in Durban, a quantitative measurement of their ultraviolet radiation doses and exposure patterns is required.

1.4 Aim, objectives and relevance of the study

The aim of this study is to quantify daily ultraviolet radiation doses and to investigate the ultraviolet radiation exposure patterns of children and adolescents in Durban. Polysulphone film (PSF) will be used to determine the daily ultraviolet radiation doses of children and adolescents. These results together with information recorded in a personal ultraviolet radiation journal will form the foundation upon which this study is based. The objectives required to meet the above-mentioned aim of the study are as follows:

(1) To measure the daily ultraviolet radiation dose of young children and adolescents, both male and female, over a one-week period during summer in Durban through the use of PSFBs.

(2) To compare the daily ultraviolet radiation dose of the children and adolescents with that received on a horizontal surface as recorded by a Yankee Environmental Systems (YES) UVB-1 pyranometer that is

located on the roof of the Desmond Clarence building at the University of Natal.

(3) To investigate the effects of behaviour and activity patterns, age, gender and skin type on ultraviolet radiation exposure patterns and doses.

(4) To consider the effect of orientation on ultraviolet radiation dose though the employment of PSF strips attached to different parts of the body of a mannequin and to relate the results to the ultraviolet radiation doses of the children and adolescents.

(5) To investigate the relationship between cloud cover and ultraviolet radiation through the use of a mannequin.

(6) To provide recommendations regarding individual behaviour in relation to ultraviolet radiation exposure, as well as to identify future studies that could serve to reinforce these initial findings.

The relevance of this study is based on the need for an accurate quantification of the ultraviolet radiation doses of children and adolescents in Durban in order to estimate short-term and long-term risks and consequently make recommendations in order to minimise the likelihood of occurrence of these adverse health effects. These findings can then be practically implemented into school curricula and other communication strategies to inform and educate the public, particularly children, adolescents, their parents and educators, of the health risks of overexposure to ultraviolet radiation.

The results of this study will provide a foundation upon which further research will be conducted and educational initiatives pertaining to the health risks associated with ultraviolet radiation exposure may be pursued. The following chapter provides an introduction to ultraviolet radiation, discusses the health effects associated with exposure to ultraviolet radiation and considers the relationship between childhood exposure to ultraviolet radiation and the occurrence of skin cancer.

Chapter Two

ULTRAVIOLET RADIATION

2.1 Introduction to ultraviolet radiation

Ultraviolet radiation is the part of the electromagnetic spectrum that lies between the visible and x-ray regions, between approximately 100 - 400 nanometers (nm) (Figure 2.1). The quantity and quality of ultraviolet radiation received at the earth's surface depends on the energy output of the sun and the transmission properties of the atmosphere (Diffey, 1991).

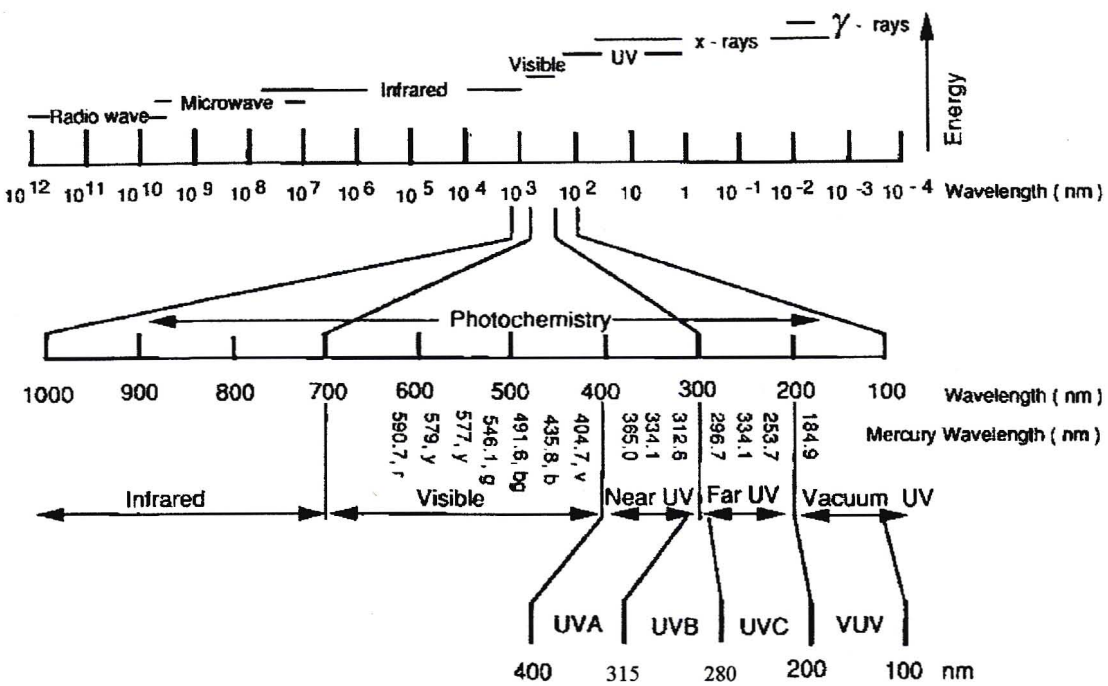


Figure 2.1: Wavelengths of electromagnetic and photochemical radiation indicating the subdivisions of ultraviolet radiation (Source: Jahan, 1990: 111)

Ozone plays an important role in absorbing ultraviolet radiation. The well-known depletion of the ozone layer has raised several concerns with regard to an expected increase of surface ultraviolet radiation. This increase in surface ultraviolet radiation has been shown to pose a direct risk to human health, particularly since the ultraviolet band of the electromagnetic spectrum is the predominant environmental risk factor in inducing detrimental effects on biological systems (Grossman, 1997).

Ultraviolet radiation may be classified into three spectral regions or bands based on their differences in causing biological damage and other characteristics. The three wavebands are UVA, UVB and UVC. There is much variation surrounding the thresholds used in the division into these spectral regions. For the purpose of this study each waveband is identified based on values suggested by Herman and McKenzie (1998) and presented in Table 2.1.

Table 2.1: Definition and description of the three bands of ultraviolet radiation (After: Herman and McKenzie (1998) and Diffey, (1986)).

Band	Common term:	Waveband	% of the solar spectrum	Description
UVA	Longwave or 'black light'	315 - 400 nm	~ 6.3%	Associated with generation of photochemical smog and fading of bright colours Causes visible effects of ageing, wrinkling and loss of skin elasticity
UVB	Middlewave or 'erythemal'	280 - 315 nm	~ 1.5%	Causes damage at the molecular level and impacts on biological systems including human skin
UVC	Shortwave or 'germicidal'	220 - 280 nm	~ 0.5%	Important in atmospheric photochemistry and theoretically, if it reached the earth's surface, it could cause the most damage as it is absorbed by DNA and proteins.

Measurements of ultraviolet radiation were initially begun in the 1920s and today a number of networks have been further extended into Europe, North and South America, Australia, New Zealand and Japan (Taalas *et al.*, 2000). These networks are based on spectral, broadband and multiband instruments. Two types of detectors are used extensively for the measurement of UVB at the earth's surface: broadband

detectors and spectroradiometers (Tevini, 1993). Measuring long-term trends in ultraviolet radiation requires long-term instrument stability. Often records are too short, frequently disrupted and instrument stability is insufficient to be able to detect long-term trends (Herman and McKenzie, 1998). Other than measurement activities, modelling of the radiative transfer of ultraviolet radiation through the atmosphere has also been intensified (Madronich *et al.*, 1995; Bodeker and Scourfield, 1998; Herman and McKenzie, 1998; Longstreth *et al.*, 1998 and Meloni *et al.*, 2000). Consequently, a theoretical understanding of the influence of factors including solar zenith angle, cloud, ozone, aerosols, surface albedo and altitude has been covered extensively in scientific literature. These factors will be discussed below.

2.2 Factors influencing ultraviolet radiation at the earth's surface

The main factors influencing solar ultraviolet radiation received at the earth's surface are solar zenith angle, total column ozone and cloud cover. Other factors include altitude, albedo, aerosols and geographical latitude or season.

2.2.1 Solar zenith angle

Solar zenith angle is one of the most critical parameters influencing clear sky ultraviolet irradiance at the surface. The solar zenith angle is the angular distance between the sun's rays and the local vertical and determines the path length of the solar beam through the atmosphere (Tevini, 1993). It is relevant for the diurnal and seasonal variation as well as for the variation with latitude (Tevini, 1993). The diurnal variation in ultraviolet radiation, or variation as a function of time of day, shows that ultraviolet radiation is received at higher intensities on the earth's surface at solar noon compared to early morning and later afternoon (Tevini, 1993).

Duigan (1995) noted that high surface ultraviolet radiation levels were associated with small solar zenith angles (summer) and low surface ultraviolet radiation levels were associated with large solar zenith angles (winter). In winter, when the sun is low in the sky and the solar zenith angle is great, there is an increased atmospheric depth through which the ultraviolet radiation must traverse. This increased path length allows for efficient scattering to take place such that the ultraviolet radiation incident upon the

surface is reduced (Duigan, 1995). Studies that have considered ultraviolet radiation receipt at the earth's surface as a function of solar zenith angle include Tevini (1993), Duigan, (1995) and Duigan *et al.* (1995).

2.2.2 Ozone

Total column ozone is one of the most important factors influencing surface ultraviolet radiation since it is the main absorber of ultraviolet radiation. Figure 2.2 shows the absorption spectrum of ozone and Table 2.2 presents these absorption tendencies in terms of the three bands of ultraviolet radiation. UVC is most strongly absorbed by ozone, however, UVB is the most sensitive to ozone levels. According to Madronich *et al.* (1995) an increase in UVB resulting from a decrease in total column ozone will have serious implications for living systems on earth, particularly human beings.

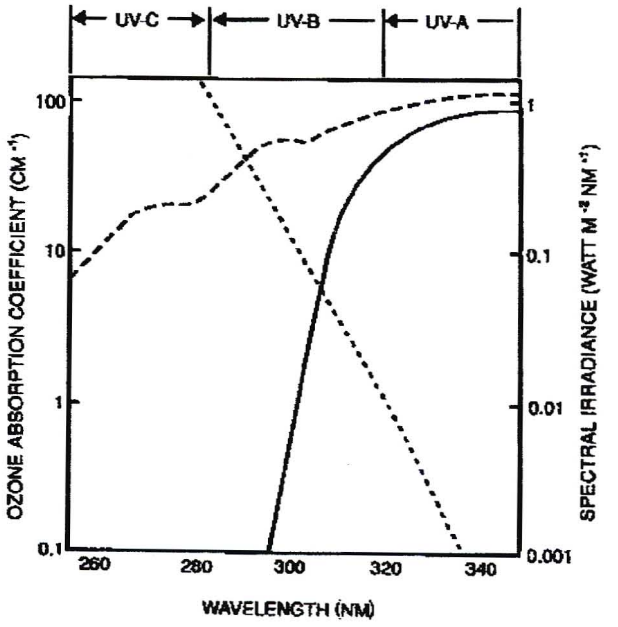


Figure 2.2: A schematic representation of the absorption spectrum of ozone (dotted line and left scale), extraterrestrial solar spectrum (dashed line and right scale) and solar spectrum at the surface of the earth (solid line and right scale) (Source: Webb, 1998: 5)

Table 2.2: Absorption tendencies of ultraviolet radiation by ozone (After: National Research Council, 1983)

Ultraviolet band	Waveband	Absorption tendency
UVA	315 - 400 nm	Largely unaffected by ozone
UVB	280 - 315 nm	Absorption by ozone is a sensitive function of wavelength and increases as the wavelength decreases
UVC	220 - 280 nm	Very strongly absorbed by ozone

An inverse relationship therefore exists between ozone and ultraviolet radiation. At times when total column ozone measurements are low, surface ultraviolet radiation levels tend to be high since there is less ozone to absorb the ultraviolet radiation (Diffey, 1991). This has been investigated in both theory and through actual measurements. Surface ultraviolet radiation may be interpreted as a function of total column ozone since long-term declines in ozone have coincided with increasing surface ultraviolet radiation levels (Herman and McKenzie, 1998).

Ozone (O_3) is a gas comprising three atoms of oxygen and is present in significant amounts in both the troposphere and the stratosphere. Ozone is formed by the action of short wavelength ultraviolet radiation of less than 240 nm on molecular oxygen in the upper stratosphere where:

$$O_2 + h\nu \rightarrow 2O$$

$$O + O_2 + M \rightarrow O_3 + M$$

where M is a third body such as N_2. Ozone is itself photodissociated by ultraviolet radiation where:

$$O_3 + h\nu \rightarrow O_2 + O$$

and in a pure oxygen atmosphere additional oxygen recombines according to:

$$O + O_3 \rightarrow 2O_2$$

The process of converting oxygen to ozone and back to oxygen is continuous and results in the formation of the ozone layer, a band of gaseous ozone in the stratosphere that absorbs ultraviolet radiation and reduces surface levels. The absorption of ultraviolet radiation by stratospheric ozone is vital for the protection of living organisms on earth (Jones, 1987).

Figure 2.3 presents, by way of an example, the relationship between surface EUV and total column ozone at Mauna Loa Observatory, Hawaii (Herman and McKenzie, 1998). The inverse relationship between the two variables is clearly evident. Confirmation of this expected theoretical relationship by means of observation is difficult due to the interplay of other factors influencing surface ultraviolet radiation levels, including cloud cover and aerosols. This particular station in Hawaii is located at a high altitude where the atmosphere is relatively free of surface-generated aerosols and pollution that may alter the measurements.

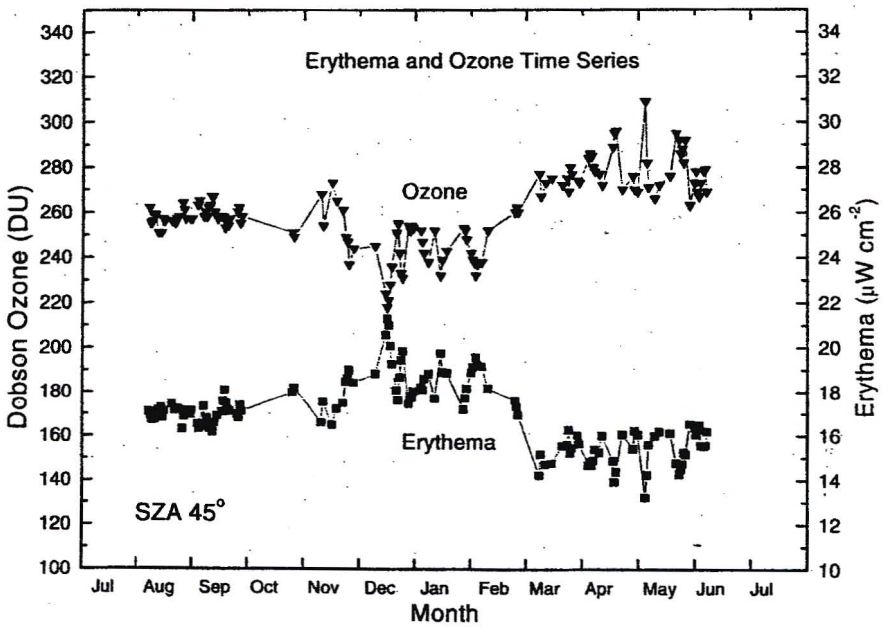


Figure 2.3: Erythemally active irradiance and total column ozone measurements at Mauna Loa Observatory, Hawaii (Source: Herman and McKenzie, 1998: 9.6)

Work at SANAE (South African Antarctica Base) has also shown that surface ultraviolet radiation levels were enhanced in the presence of the Antarctic ozone hole and a clear inverse relationship was visible when comparing surface ultraviolet

radiation measurements with total column ozone data (Prause *et al.*, 1999). Other studies that have considered this inverse relationship between ozone and ultraviolet radiation include Tevini (1993), Duigan *et al.* (1995), Longstreth *et al.* (1998) and Bodhaine *et al.* (1996).

2.2.3 Clouds

The relationship between cloud cover and ultraviolet radiation is complex as clouds may serve to either enhance or reduce surface ultraviolet depending upon various parameters, including the relative position of the sun, optical cloud depth, cloud type and water droplet size distribution (Aida, 1977; Diffey, 1991; Estupinan *et al.*, 1996). A number of theoretical, empirical and combined approaches have been used to approximate the impact of cloud cover on ultraviolet radiation at the earth's surface.

Generally, cloud cover has been described as being responsible for short-term changes in surface ultraviolet radiation with less of an impact on long-term trends (Duigan, 1995). However, measuring the relationship between cloud cover and surface ultraviolet radiation is not a straightforward task. In traditional meteorological observations cloud amounts are usually given according to an integer scale ranging from 0 - 8, with units known as 'octas' (Jossefsson and Landelius, 2000). The type and height of the cloud may also be recorded. However, since cloud cover is variable, both spatially and temporally, it is often difficult to record these changes in a highly accurate manner.

Other than direct observation, modelling of the relationship between cloud cover and ultraviolet radiation has been undertaken, often focusing upon homogenously overcast conditions although fractional cloud cover has also been included (Bordewijk *et al.*, 1995). Bodeker and McKenzie (1996) derived an algorithm for inferring long-term trends in surface ultraviolet radiation at a specific location taking into account cloud cover. They stated that cloud cover poses a number of difficulties for surface ultraviolet irradiance modelling due to the high variability of cloud characteristics, its spatial inhomogeneity and temporal variability. The type and height of clouds may strongly affect the transmission of ultraviolet radiation through the lower atmosphere (Nemeth *et al.*, 1996). Factors considered in these models include cloud type, cloud

location in relation to the direct solar beam, percentage cloud cover, cloud optical thickness, liquid content and particle size distribution (Estupinan *et al.*, 1996; Frederick and Snell, 1990). A sky–cloud formula derived by Sabburg and Wong (2000) considered cloud brokenness, cloud brightness, angle of maximum cloud cover and aureole brightness and found that surface ultraviolet radiation was enhanced under broken cloud conditions when the solar disk was obscured, although still visible.

Uniformly overcast skies are known to suppress surface ultraviolet radiation levels (Bodeker and McKenzie, 1996). Under thick overcast cloud layers ultraviolet irradiance at all wavelengths may be approximately 20% of that received under clear sky conditions (Lubin and Frederick, 1991; Nemeth *et al.*, 1996). The most fundamental cloud property under overcast conditions is optical cloud depth such that the solar disk is either visible through the cloud layer or completely obscured. Precipitating clouds tend to be less transparent than non-precipitating clouds (Jossefsson and Landelius, 2000) and thus surface ultraviolet radiation levels are further depressed under densely overcast conditions.

Partly cloudy conditions may either reduce or enhance surface ultraviolet radiation levels depending on the geometry of the cloud cover and the relative position of the sun (Bodeker and McKenzie, 1996). Partly cloudy skies where the sun is not obscured by clouds may enhance surface ultraviolet irradiance by 25% above clear sky conditions (Nack and Green, 1974). This is due to additional reflection from the edges of the clouds towards the ground (Nemeth *et al.*, 1996; Weihs *et al.*, 2000).

Surface albedo may play an important modulating role in conjunction with cloud cover in enhancing surface ultraviolet irradiance (Seckmeyer *et al.*, 1996). Herman and McKenzie (1998) state that measurements made at Raleigh, North Carolina show that surface ultraviolet radiation increases up to 27% under partly cloudy skies consisting mainly of cumulus clouds. Renaud and Staehelin (2000) noted that surface ultraviolet radiation may be reduced by 70% relative to clear sky conditions for a thin cloud layer where the solar disk is not obscured by the cloud.

2.2.4 Altitude

Ultraviolet radiation levels increase in intensity with increasing elevation due to the presence of a thinner atmosphere to absorb the ultraviolet radiation (Madronich *et al.*, 1995). The increase in ultraviolet radiation with higher altitudes is known as the 'altitude effect' and depends on elevation due to the varying amount of irradiated air mass and on wavelength due to stronger scattering at shorter wavelengths (Tevini, 1993). A definite rate of change in irradiance for changes in altitude has not been defined since altitude dependence varies according to solar zenith angle and wavelength (Herman and McKenzie, 1998).

A study conducted in Germany found that surface erythemal ultraviolet radiation was between 25 - 90% higher at an altitude of three km compared to an altitude of 0.73 km over a five month period (Herman and McKenzie, 1998). A comparison made at two stations in Switzerland showed an increase of 8% per km in ultraviolet radiation, 9% per km for UVA and 18% per km for EUV in summer (Herman and McKenzie, 1998). Thus the risk of overexposure and adverse impacts caused by ultraviolet radiation appears to increase with altitude.

2.2.5 Albedo

The albedo of a horizontal surface is defined as the ratio of reflected radiation to incident radiation. It is a function of surface material, texture and wavelength (Taalas *et al.*, 2000). Albedo affects ultraviolet radiation by enhancing diffuse radiation and in this manner increasing surface ultraviolet radiation levels (Madronich *et al.*, 1995). A surface with a high albedo will have a greater ability to reflect surface ultraviolet radiation. A high albedo for snow cover in conjunction with backscatter from the lower atmosphere may lead to the further intensification of surface ultraviolet radiation (Taalas *et al.*, 2000). Reflections from water, land and vegetation may directly increase the ultraviolet radiation directly by illuminating the atmosphere from below, which then scatters ultraviolet radiation back to the surface (Madronich, 1993).

2.2.6 Aerosols

The presence of aerosols, described as small suspended, solid or liquid particles, in the atmosphere may lead to the attenuation and scattering of ultraviolet radiation through Mie scattering, thereby reducing surface ultraviolet radiation levels (Jahan, 1990). The concentration of aerosols and their size-distribution is important in terms of atmospheric turbidity that leads to the scattering and absorption of solar radiation (Tevini, 1993). Tropospheric aerosols, for example mineral dust, sea-salt particles, soot, ammonium sulphate and diluted sulphuric droplets, significantly reduce ultraviolet radiation levels in polluted areas (Madronich *et al.*, 1995). Aerosols may have an impact on the radiative transfer of ultraviolet radiation in polluted areas, in conditions of forest fires and biomass burning. In these instances aerosols may attenuate between 20 - 45% of the incoming ultraviolet radiation (Taalas *et al.*, 2000).

A secondary impact of aerosols on ultraviolet radiation involve ozone depleting substances such as CFCs, HCFCs, halons, methyl bromide, carbon tetrachloride and methyl chloroform which are generally stable in the atmosphere but degrade when exposed to short wavelength ultraviolet radiation in the stratosphere (McKenzie *et al.*, 1998). When they dissociate they release radicals which are efficient catalytic destroyers of ozone, for example, chlorine and bromine (Jones, 1987).

A number of mechanisms have been suggested to account for the ozone loss by these catalysts (X) but in general:

$$X + O_3 \rightarrow XO + O_2$$

$$XO + O \rightarrow X + O_2$$

$$O + O_3 \rightarrow 2O_2$$

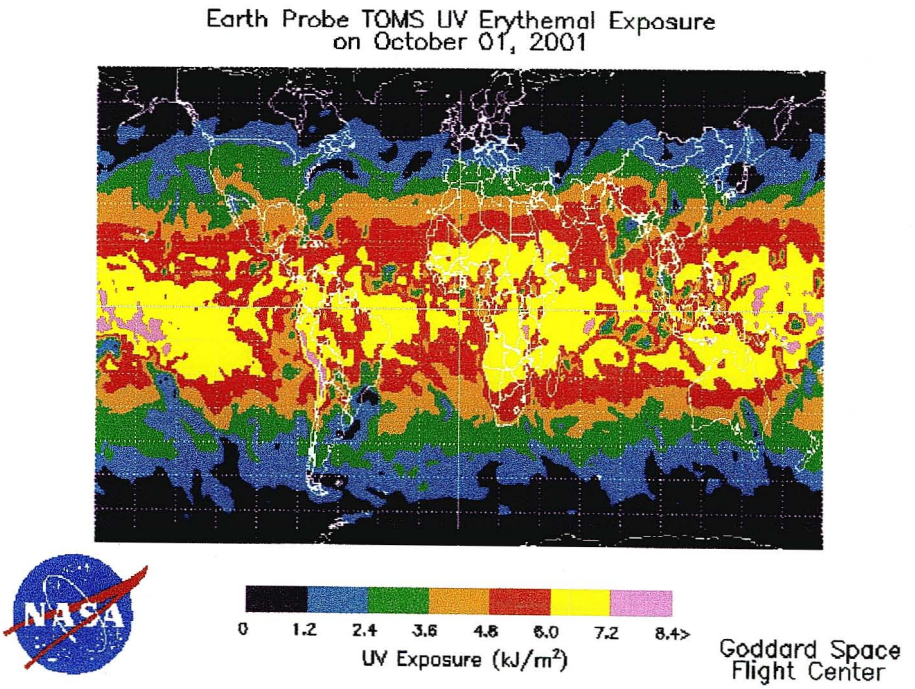
where X may be Cl, OH, NO or BrO. The source gases may be either natural or a result of human activities. Thus, aerosols provide the surface where ozone destruction reactions may take place and therefore improve a catalyst's effectiveness at playing a role in ozone depletion.

2.2.7 Geographical latitude and season

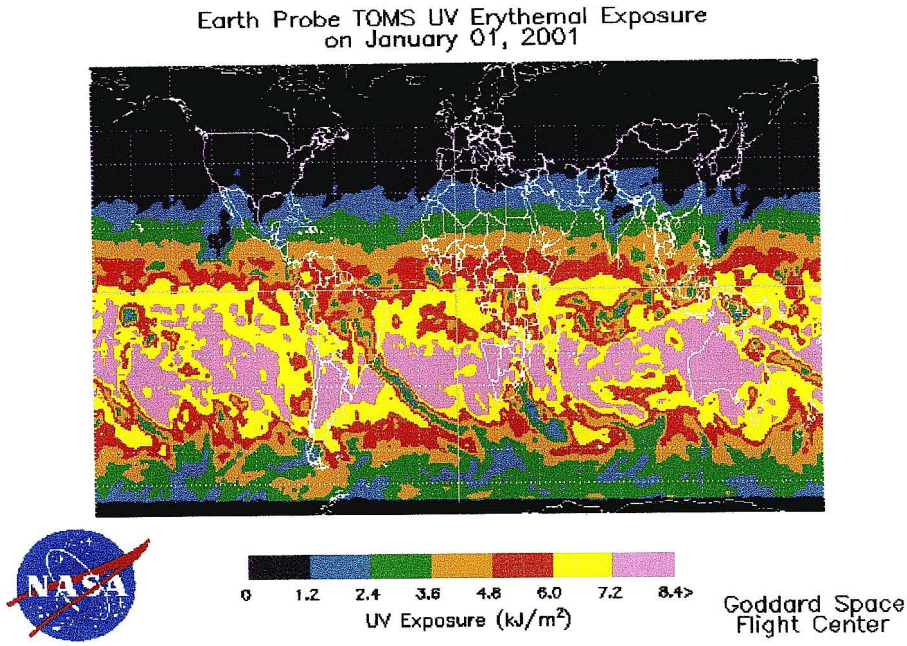
Ultraviolet radiation flux at the earth's surface tends to decrease as the geographical latitude increases. Therefore, with increasing distance from the equator the solar zenith angles increase and total column ozone levels may increase resulting in lower surface ultraviolet radiation levels (Bodeker and Scourfield, 1998). This indicates that locations situated in close proximity to the equator may experience higher ultraviolet radiation levels, as well as smaller variations in annual and seasonal ultraviolet radiation trends (Diffey, 1991).

The global trends in ambient EUV for the four seasons of the year 2000 are presented in Plate 2.1 and illustrate both the latitudinal and seasonal variations in surface ultraviolet radiation. TOMS (Total Ozone Mapping Spectrometer) instruments provide these satellite images of EUV patterns using radiative transfer models and measured irradiance (Herman and McKenzie, 1998). During the Southern Hemisphere summer the highest amount of ambient EUV is evident over mid-latitude regions incorporating South Africa.

(a)



(b)


Earth Probe TOMS UV Erythemal Exposure
on January 01, 2001
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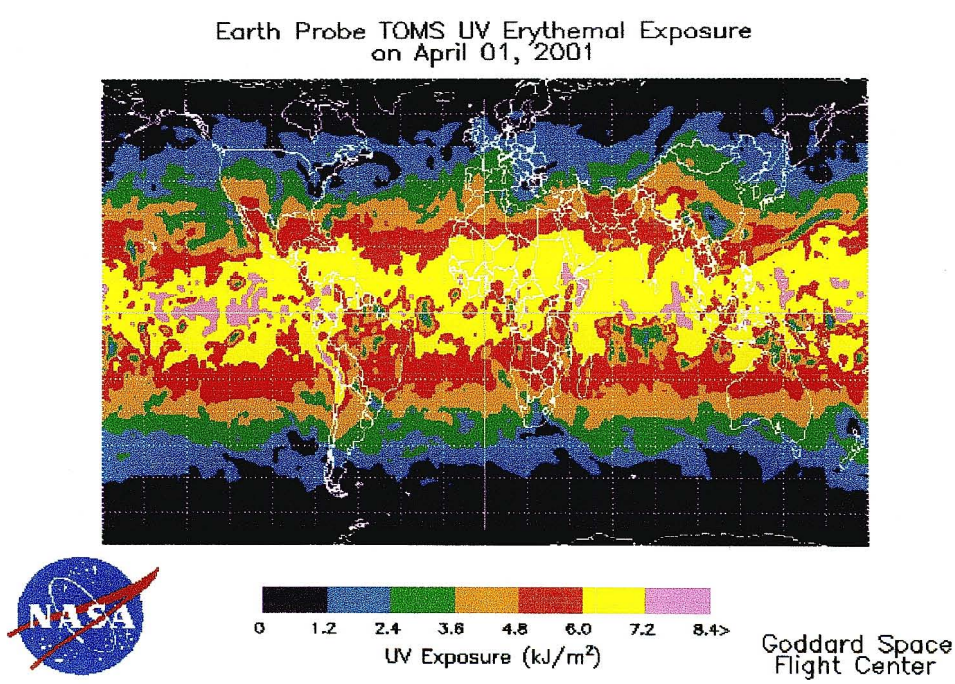
UV Exposure (kJ/m²)
Goddard Space
Flight Center

(c)


Earth Probe TOMS UV Erythemal Exposure
on April 01, 2001
0 1.2 2.4 3.6 4.8 6.0 7.2 8.4>
UV Exposure (kJ/m²)
Goddard Space
Flight Center

(d)

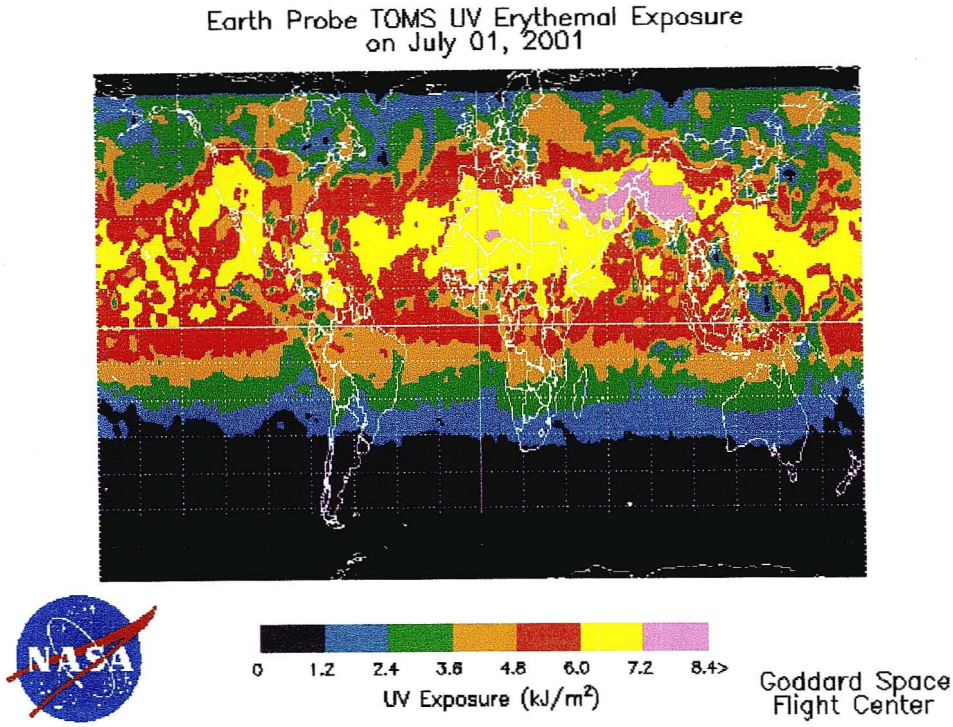


Plate 2.1: TOMS satellite images showing the global pattern in surface EUV for (a) 1 October 2001, (b) 1 January 2001, (c) 1 April 2001 and (d) 1 July 2001 (Source: NASA, 2001)

The seasonal changes in surface ultraviolet radiation levels are dependent upon the hemisphere and the distance from the equator (Diffey, 1991). Levels are usually greater in summer when the sun's direct rays are overhead, however, the variation becomes less defined at locations closer to the equator. These variations have been explained due to the known differences in total column ozone and earth-sun separation (Herman and McKenzie, 1998). Surface ultraviolet radiation levels tend to be consistently larger in the Southern Hemisphere due to smaller earth-sun separation during the Southern Hemisphere summer and also due to the lower values of Southern Hemisphere stratospheric ozone (Madronich, 1993).

2.3 Biological effects of ultraviolet radiation on human health

The biological effects of solar ultraviolet radiation on human health can be categorised according to three major organ systems of the human body:

- Visual system, e.g. cataracts and photokeratitis (snowblindness)
- Immune system, e.g. immunological suppression (immuno-suppression), herpes simplex
- Human skin, e.g. acute effects including vitamin D_3 production, tanning, erythema (sunburn) and melanin pigmentation; chronic effects including photo-ageing, skin cancer, both non-melanoma skin cancer (NMSC) and malignant melanoma skin cancer (MMSC)

Each of these will be discussed, with particular emphasis on the impacts of ultraviolet radiation on the skin. Common to all impacts of ultraviolet radiation on biological systems is the concept of an 'action spectrum'. This is described as the wavelengths producing an observable biological effect (Parrish *et al.*, 1978). The biologically active irradiance is obtained by multiplying surface irradiance by an appropriate weighting function or action spectrum. It is those wavelengths that are absorbed by a molecule to initiate the photochemical events that then lead to the observed effect, for example erythema or photo-ageing of the skin.

It is acknowledged that ultraviolet radiation is used in clinical medicine for the treatment of certain human skin diseases. For example, psoralen photochemotherapy, or PUVA involves the combination of photo-active drugs with longwave ultraviolet radiation (UVA) to treat skin diseases (Diffey, 1986). Ultraviolet radiation is also used to treat patients with skin diseases such as psoriasis, however, a discussion of these beneficial effects is not included in this study.

2.3.1 Ultraviolet radiation and its effects on the visual system

Ocular exposure, or exposure of the eye, to ultraviolet radiation is associated with several changes in the structure of different parts of the eye including the lens, cornea and retina. Each of the target tissues in the eye has a different action spectrum for ultraviolet radiation-induced damage, where most biological damage has a higher relative effectiveness at the shorter UVB and hence more energetic wavelengths of the ultraviolet radiation band (Parisi *et al.*, 2001). Diffey (1991) confirms that UVB is the

most damaging part of the ultraviolet radiation spectrum in terms of the effects on the eye and are relatively similar for individuals of all skin types (Armstrong, 1994).

The eyes are principal routes of exposure to ultraviolet radiation and tend to experience negative effects as a result of cumulative ultraviolet radiation exposure, except in the case of photokeratitis (Figure 2.4). When sunlight impinges upon the eye, the cornea is the first to encounter the ultraviolet radiation, followed by the lens, vitreous humour and retina (Longstreth *et al.*, 1998). Studies indicate that due to its absorption by various molecules in the cornea and lens, most ultraviolet radiation never reaches the retina in an adult eye (Longstreth *et al.*, 1998).

The eye itself is protected to a certain extent from ultraviolet radiation by its position in the eye socket and under the eyebrow (Tevini, 1993). This shielding is most effective with a high sun during midday (Tevini, 1993). Work conducted by Parisi *et al.* (2001) shows that there is a higher percentage of the diffuse component of ultraviolet radiation at the shorter UVB wavelengths, recognised as most dangerous to the eye, in the early morning and late afternoon.

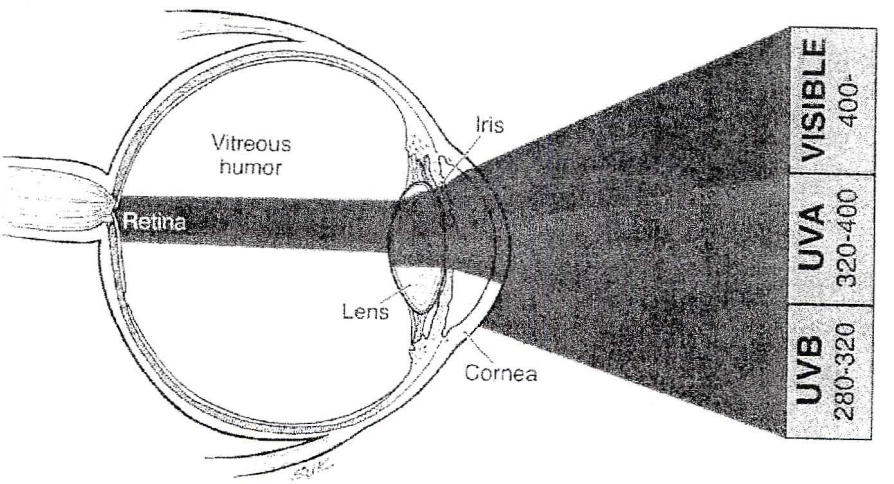


Figure 2.4: Absorption of ultraviolet radiation by the eye (Source: UNEP, 1998: 32)

The adverse effects of UVB on the eye have only recently been quantified through epidemiologial studies in humans (Taylor, 1989). These studies have used methods including direct measurements with PSF dosimeters, PSF contact lenses, PSF attached to an eyeglasses frame and by the development of models (Parisi *et al.*, 2001). These

methods, combined with detailed ultraviolet radiation exposure histories, have allowed investigators to correct for the variation in individual exposure and thus eliminate the 'ecological fallacy', the assumption that all individuals in a given location are equally exposed to ambient ultraviolet radiation levels of that particular location (Taylor, 1989).

2.3.1.1 Impacts on the lens

Ultraviolet radiation absorbed by the lens of the eye over time may result in changes in the lens. The most common consequence of this is the occurrence of a cataract, an opacity or clouding of the lens which then impairs vision and may cause blindness (Tevini, 1993). There are three types of cataracts: cortical, nuclear and posterior subcapsular. A consistent dose-dependent association between the formation of these cataracts and ocular UVB exposure has been shown (Taylor, 1989). Cortical cataracts develop on the outer layers of the lens protein or cortex of the lens, while posterior subcapsular cataracts develop at the back of the lens at the interface between the lens and the epithelial capsule (Longstreth *et al.*, 1998). Cataracts have been identified as the leading cause of blindness in the world (Longstreth *et al.*, 1998).

The case study commonly referred to in relation to cataracts is that of the 838 Chesapeake Bay (Maryland, USA) fishermen, previously known as watermen (Taylor, 1989; Diffey, 1991; Armstrong, 1994). Approximately 13% of the fishermen had cortical cataracts. These men had a 21% higher average annual UVB exposure than those without cataracts. This study showed a clear, consistent relationship between the development of cortical cataracts and established ocular UVB exposure (Diffey, 1991).

In 1985, 17 million people in the world were diagnosed as having cataracts, 13 million were located in developing countries and 4 million in developed countries (Armstrong, 1994). A geographical relationship between cataracts and ultraviolet radiation exists such that there is a worldwide prevalence for the incidence of cataracts to increase with increasing proximity to the equator (Armstrong, 1994).

2.3.1.2 Impacts on the cornea

Excessive ultraviolet radiation exposure, particularly ultraviolet radiation reflected from sand, snow and tar, can produce a 'burn' on the surface of the eye or cornea known as photokeratitis (Diffey, 1991). It is the most common acute effect of ultraviolet radiation on the ocular system (Longstreth *et al.*, 1998). Described as the ocular equivalent of sunburn, photokeratitis produces an inflammation and reddening of the eyeball, a gritty feeling of severe pain, tearing and blepharospasm, or twitching (Longstreth *et al.*, 1998).

Photokeratitis, or snowblindness, occurs mostly in individuals who spend time on snowfields or in the desert where ambient UVB levels are high (Diffey, 1991). It is estimated that approximately two hours of ultraviolet radiation exposure around noon on snow-covered terrain is sufficient to induce photokeratitis, while an exposure period of 6 - 8 hours may be needed in sandy terrain (Diffey, 1991). This association between UVB exposure and photokeratitis, an acute photo-toxic corneal disorder (Taylor, 1989), is now clearly established and well recognised.

A second impact of excessive ultraviolet radiation on the cornea is the development of a fleshy growth over the cornea, known as a pterygium (Diffey, 1991). Pterygiums may develop extensively across the cornea and progressively obstruct vision. Outdoor workers have approximately three times the risk of developing pterygiums compared with indoor workers.

2.3.1.3 Impacts on the retina

Long-term ultraviolet radiation exposure has been associated with damage to the retina, located at the back of the eye, and contributing towards macular degeneration and vision loss, particularly in individuals over the age of 55 years (Taylor, 1989). In adults, the cornea and the lens protect the retina from almost all radiation below 400 nm (Armstrong, 1994). However, the lens of a child is more transparent allowing up to 4% of radiation in the waveband 300 - 340 nm to reach the retina and increasing their risk of solar retinopathy (Armstrong, 1994).

Taylor (1989) conducted a case-control study that attempted to assess ocular exposure to ultraviolet radiation in relation to intra-ocular malignant melanoma by obtaining a behavioural history of each individual. This included information on their birthplace, use of eye protection, use of tanning beds/sunlamps, sunbathing habits and leisure sun exposure. The study showed that exposure to solar ultraviolet radiation, particularly during childhood, may be important in the development of intra-ocular malignant melanoma that is the most common ocular malignancy (Longstreth *et al.*, 1998).

2.3.2 Ultraviolet radiation and its effects on the immune system

Ultraviolet radiation has been associated with the suppression of the human immune system and its ability to fight disease as well as the initiation of certain viruses. The immune system itself is complex with several subsystems inducing or suppressing each other (Tevini, 1993). It is relatively unknown as to what role ultraviolet radiation, and UVB in particular, plays in terms of the immune system. However, there is experimental evidence to support the fact that enhanced ultraviolet radiation on human skin selectively inhibits certain cellular mediated immune responses (Duigan, 1995).

Ultraviolet radiation incident upon the skin mediates certain changes in the Langerhans cells, cells that reside in or migrate through the epidermis (Tevini, 1993). Since the skin is the front line defence mechanism against foreign agents such as viruses, these Langerhans cells play a vital role in protecting the body such that any change in their structure induced by ultraviolet radiation exposure may have implications for the effectiveness of their response (Longstreth *et al.*, 1998).

Immuno-suppression effects of ultraviolet radiation can result in adverse circumstances: too much suppression can render an individual susceptible to infections and too little could result in skin-damaging inflammatory reactions upon exposure to ultraviolet radiation (Longstreth *et al.*, 1998). Recent observations show that ultraviolet radiation exposure can activate or reactivate latent infections and viruses such as the herpes simplex virus (Urbach, 1989a). Most commonly found on the lips and genitalia of humans, the herpes infection is accentuated upon exposure to ultraviolet radiation (Urbach, 1989a).

Suppression of the immune system due to exposure to ultraviolet radiation is independent of skin type (Armstrong, 1994) and therefore affects all populations. Experimental studies have shown that photo-induced alterations of the immune response system in mice play an important role in the formation of UVB-induced skin cancer (Duigan, 1995). Damage at the cellular level together with suppressed immune response mechanisms may provide for the growth of certain cancers in any individual, irrespective of skin type (Armstrong, 1994). There is also concern for the impacts of UVB in terms of immunisation programmes and the administering of vaccines. Studies have shown that apart from affecting the development of immunity to natural infections, UVB may also impair the response of individuals to immunisations that use live, attenuated virus vaccines such as the measles vaccine and BCG (Armstrong, 1994).

Goettsch *et al.* (1998) conducted a '*Risk assessment for the harmful effects of UV-B radiation on the immunological resistance to infectious diseases*'. They extrapolated the experimental evidence of the effects of ultraviolet radiation on the immunological resistance to infectious diseases in rats to estimate the risk for humans exposed to increased ultraviolet radiation. The results of the study showed that one of the major effects of UVB exposure is the suppression of the immune system and of the natural killer cell function found in the human body (Goettsch *et al.*, 1998). Even low doses of UVB were found to impair the immune system. Thus, it was concluded that UVB is a potential hazard to immunological functioning and resistance against infectious disease in the human body. A primary concern is that these immunological changes may contribute towards the development of human skin cancers including NMSC and MMSC (National Research Council, 1983).

2.3.3 Ultraviolet radiation and its effects on human skin

A number of biological effects of ultraviolet radiation on human skin take place immediately following exposure to ultraviolet radiation within the epidermal and dermal layers of the skin (Parrish *et al.*, 1978). Changes in biophysical and photochemical molecular events are preceded by alterations in cellular biochemistry, metabolism, structure and functioning only a few hours after exposure (Parrish *et al.*,

1978). In order to understand the nature of these events a brief description of the human skin is provided.

The skin is a unique organ of the human body that is more than just an inert sheath (Pathak, 1990). It performs a number of functions including: preventing loss of body fluid; regulating thermal homeostasis; protecting against mechanical forces on underlying organs; retarding the entrance of toxins and pathogens that cause injury and disease; and maintaining defence mechanisms against acute and chronic effects of ultraviolet radiation such as melanin production (Pathak, 1990). The skin's response to ultraviolet radiation is a reparative and protective response (Parrish *et al.*, 1978).

Figure 2.5a shows the three major tissue layers of the skin: the epidermis, dermis and subcutaneous tissue. The epidermis consists of keratinocytes and the stratum corneum, while the dermis is a much thicker layer with fewer cells and consisting mostly of connective tissue, blood vessels, nerves and lymphatics (Parrish *et al.*, 1978). The subcutaneous tissue contains mainly fatty tissue acting as an insulator and shock absorber.

The basal layer of the epidermis contains melanocytes that produce the pigment granules housing melanin (Figure 2.5b) (Parrish *et al.*, 1978). Melanin, a complex macromolecule and protein derived from tyrosine, strongly absorbs ultraviolet radiation and thus plays a photo-protective role in the skin. Melanin acts as a filter to screen out harmful ultraviolet radiation from the epidermis and dermis. It absorbs the ultraviolet radiation and dissipates the absorbed energy into heat thereby shielding nuclear DNA from harmful alterations (Pathak, 1990). In skin types that contain high levels of active epidermal melanin molecules it provides a front line defence against ultraviolet radiation.

The complex structure of the skin creates a variation of optical pathways which ultraviolet radiation may follow (Parrish *et al.*, 1978). Figure 2.5c illustrates the four basic optical processes that may occur in any given layer of the skin. These include direct transmission through the layer into the underlying layer, scattering by molecules, particles, organelles and cells within the layer, absorption and dissipation within a layer and direct reflection at the boundary of the layer (Parrish *et al.*, 1978).

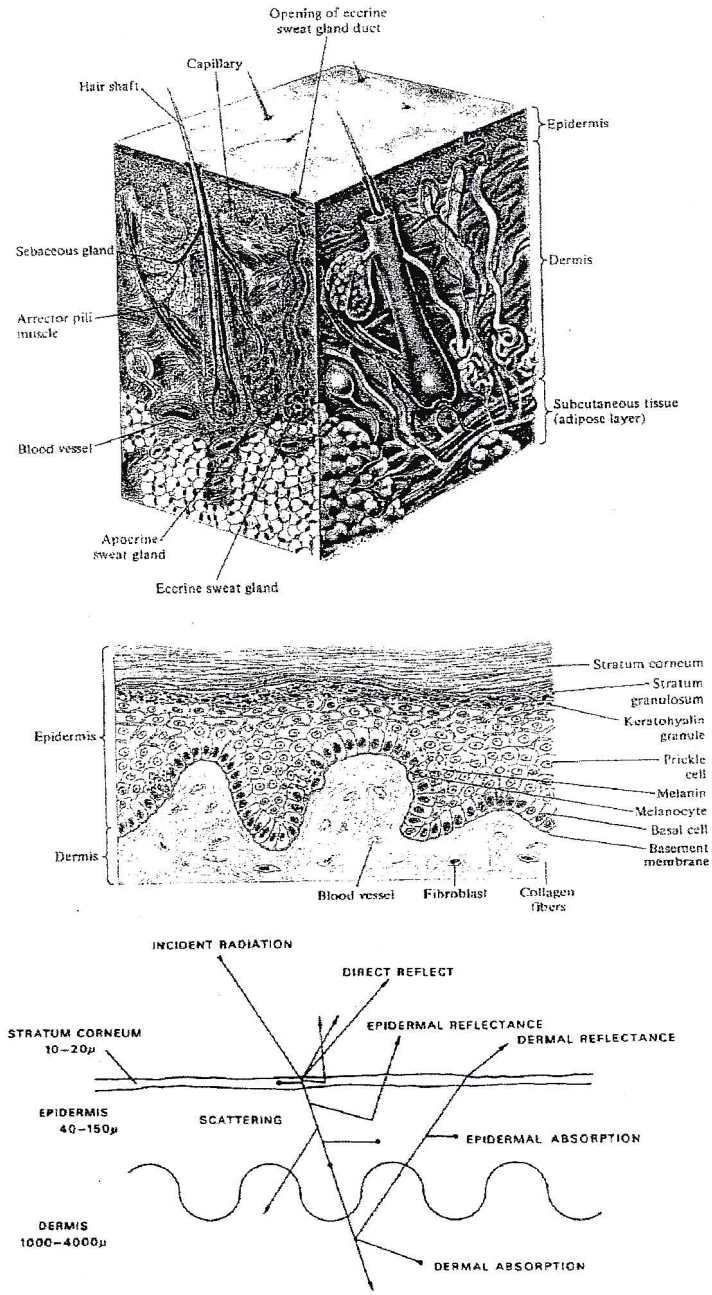


Figure 2.5: Diagrammatic sketches of various elements of the human skin (a) three major tissue layers of the skin; (b) cells of the epidermis and dermis; and (c) four optical pathways of ultraviolet radiation on the skin (Source: Parrish *et al.*, 1978: 60 - 61)

Figure 2.6 presents the estimated penetration depths of UVA, UVB and UVC. Ultraviolet radiation has a low penetrating property that is restricted to the epidermis and dermis (Orton, 1986). A number of factors influence these penetrating properties including the optical processes mentioned above, melanin, hair cover and surface lipids

(Pawin, 1999). UVA and UVB penetration sites are comparatively deeper than UVC, however, UVA penetrates the dermis, while UVB only reaches the epidermis. UVB tends to be more biologically active in the stratum corneum and epidermis producing visible damage and UVA induces less perceptible damage in the lower dermis (Pawin, 1999).

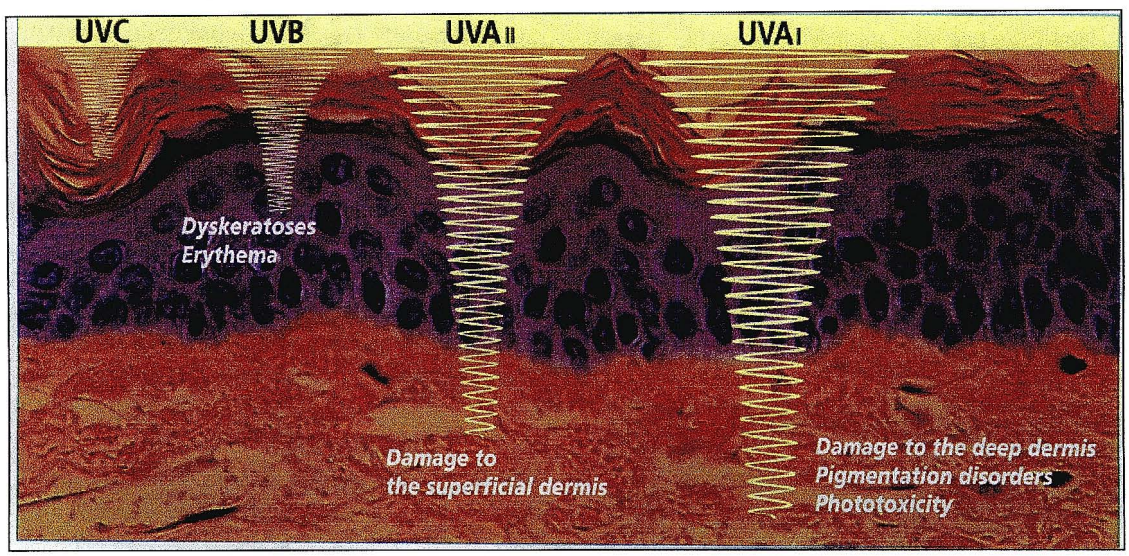


Figure 2.6: Diagram revealing the different levels of absorption of ultraviolet radiation in the skin (Source: Pawin, 1999: 4)

The biological effectiveness of ultraviolet radiation at a particular wavelength is usually determined according to an action spectrum (Horneck, 1995). An action spectrum describes the actual rate of damage to an organism as a function of wavelength and depending on the susceptibility of the organism (Lubin and Frederick, 1991; Armstrong, 1994). There is a different action spectrum for each of the biological effects induced by ultraviolet radiation in humans. The most pertinent of these are discussed below.

2.3.3.1 Acute effects of ultraviolet radiation

(a) Vitamin D_3 production

One of the beneficial effects of ultraviolet radiation is the synthesis of vitamin D_3 (Orton, 1986). Vitamin D_3 is necessary for the formation and maintenance of the human bone system (Tevini, 1993). This vitamin plays a vital role in calcium

absorption, calcification of bones and reducing the likelihood of rickets in children (Parrish *et al.*, 1978). Vitamin D_3 is further transformed by the liver and kidneys to biologically active molecules that then act on the mucosa of the intestine to facilitate further calcium absorption and calcium exchange (Orton, 1986).

Vitamin D_3 can be received in small amounts via an individual's diet but its formation in the skin forms an important part of the supply (Tevini, 1993). Exposure to ultraviolet radiation photochemically converts 7-dehydrocholestrol in the epidermis to previtamin D_3. This previtamin then isomerises to produce vitamin D_3 in a temperature-controlled reaction mediated by the skin that takes approximately three days to complete (Duigan, 1995). Vitamin D_3 then enters the blood stream and is transported to the liver where it can then take part in other metabolic processes (Diffey, 1991). Relatively short, ultraviolet radiation exposure periods of approximately 15 minutes are required for this process to take place (Duigan, 1995).

The formation of vitamin D_3 in the skin is self-limiting and thus overexposure to ultraviolet radiation will not lead to the formation of an abundance of vitamin D_3 in the form of intoxication (Armstrong, 1994). Diffey (1991) states that increased amounts of melanin pigmentation in the skin can limit the production of vitamin D_3. Deficiencies of vitamin D_3 occur in groups of dark-skinned individuals as well as in elderly people who remain indoors during most of the day (Tevini, 1993).

(b) Tanning

Tanning is the delayed pigmentation of the skin that becomes increasingly noticeable up to two days after exposure to ultraviolet radiation and may gradually increase for several days as melanin is produced (Diffey, 1986). Melanin pigmentation of the skin is evident in two forms: constitutive skin colour is the 'baseline' colour of the skin seen in different races and is determined by genetic factors. Facultative skin colour is the reversible increase in melanin that is induced upon exposure to ultraviolet radiation (Diffey, 1991). The facultative tanning response may be divided into immediate tanning and delayed tanning.

Immediate pigment darkening, also known as immediate tanning or the Meriowsky

phenomenon, takes place within minutes after the point of first being exposed to ultraviolet radiation and may continue to darken if exposure continues (Parrish *et al.*, 1978). Brief exposure to ultraviolet radiation may induce slight to moderate immediate tanning but fades within an hour after discontinuation of exposure and is barely noticeable 8 hours later. Prolonged exposure may induce a very pronounced immediate tanning effect that may last longer than 36 hours, particularly in individuals who have high levels of constitutive melanin (Parrish *et al.*, 1978).

Delayed tanning or melanogenesis may be noticeable approximately 72 hours following ultraviolet radiation exposure and persist for a period of days to weeks (Diffey, 1991). It is associated with UVB exposure, while immediate tanning is associated with UVA exposure (Parrish *et al.*, 1978). The action spectrum for delayed pigmentation closely resembles that of the erythemal action spectrum (Diffey, 1991). The skin appears to darken as melanocytes in the basal layer increase their productivity, new melanin is formed and spreads throughout the epidermis. The increase in melanin granules throughout the epidermis is thought to offer a moderate degree of photo-protection to the underlying layers including the dermis and the blood vessels (Parrish *et al.*, 1978). Other than the increase in melanin, accelerated cell division causes an increase in the thickness of the epidermis and eventual scaling of the cells (peeling). However, neither the thickening of the epidermis nor the additional melanin is an effective sunscreen for light-skinned individuals (Phillips, 1983).

(c) Erythema

Erythema is the most widespread acute form of solar damage to the skin (Longstreth *et al.*, 1998). UVB exposure has been identified as the primary tautological factor inducing erythema (Diffey, 1986 and Longstreth *et al.*, 1998). It is an injury characterised by a reddening of the skin resulting from the dilation of blood capillaries and in severe cases with subsequent blistering and peeling (Harm, 1980). It consists of a vascular reaction of the skin to ultraviolet radiation, augmented blood flow and increased vascular permeability (Phillips, 1983). This is accompanied by a feeling of tenderness and warmth due to the enlargement of the blood vessels. Large doses of ultraviolet radiation have the ability to destroy cells in the epidermis and the accumulation of serum and white blood cells causes the formation of a blister (Phillips,

1983). Small ultraviolet radiation doses cause a faint, transient redness. Figure 2.7 indicates three levels of erythema: minimal, painful and severe, where the level of damage caused in the epidermis, dermis and underlying tissue is also illustrated.

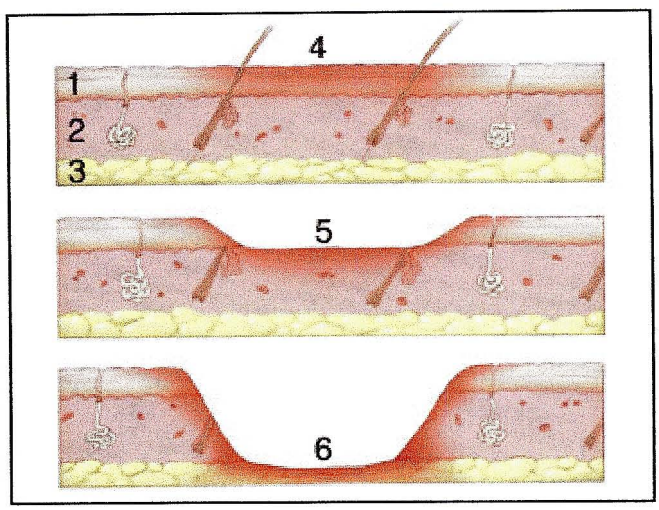


Figure 2.7: The three regions of the skin: (1) epidermis (2) dermis (3) underlying tissue and three types of erythema (4) minimal (5) painful (6) severe (Source: Broomfield, 2001)

The time course of erythema begins approximately four hours after exposure to ultraviolet radiation and reaches a maximum between 8 - 12 hours thereafter, then fading within 1 - 2 days (Diffey, 1991). Thus the erythemal reaction is biphasic consisting of immediate erythema lasting 1 - 2 hours and followed by a latency period resulting in a delayed reaction (Occupational Health and Safety Series, 1985). The delayed erythemal response is the reaction commonly known as sunburn and may take 12 - 24 hours to reach its peak (Parrish *et al.*, 1978, and Epstein, 1990).

The action spectrum for ultraviolet radiation-induced erythema refers to the effectiveness of ultraviolet radiation at different wavelengths in producing erythema, i.e. it is a wavelength dependent function that weights the ultraviolet irradiances at each wavelength according to the extent to which it induces erythema (Bodeker and Scourfield, 1998). This action spectrum has been subject to experimental and theoretical interest for almost 70 years (CIE, 1997). The Commission Internationale d'Eclairage (CIE) first considered adopting the standard erythemal action spectrum in 1935 and has since utilised the results of 8 published studies, conducted between 1964 and 1982, in accepting the reference erythemal action spectrum as an international

standard in 1987 (CIE, 1987). The reference action spectrum is found to be a valid predictor of erythemal effectiveness in human skin (CIE, 1987). Other advantages of this action spectrum are its simple graphical representation that covers the UVA region and its derivation from scientific data (CIE, 1997).

According to this erythemal action spectrum, UVB is identified as the primary cause of erythema in human skin (Figure 2.8). The relative sensitivity is highest between 240 - 300 nm, however UVC does not reach the earth's surface. It then decreases between 300 - 330 nm, yet is still relatively high and includes part of the UVB waveband. This may have implications in terms of an increase in the occurrence of erythema in view of the fact that stratospheric ozone depletion causes an increased transmission in the UVB range (Diffey, 1991).

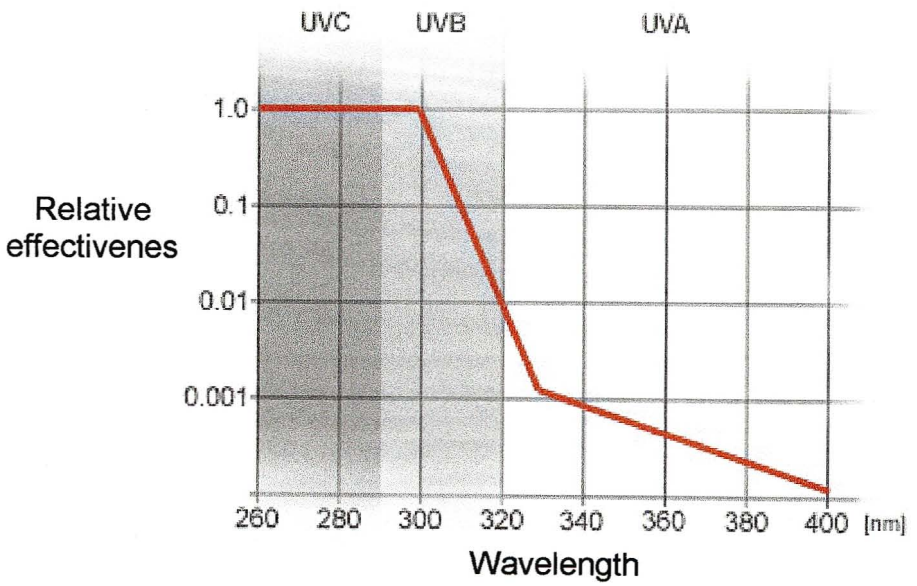


Figure 2.8: C.I.E. erythemal action spectrum (Source: Optic Tech Inc, 2001)

The skin's sensitivity to erythema was used to develop the Fitzpatrick skin phototype classification system of sun-reactive skin types (Table 2.3) (Figure 2.9). There are six skin types, each with variable skin reactions and unique erythemal responses to ultraviolet radiation exposure.

Table 2.3: Sun-reactive skin types (Adapted from: Diffey, 1991; Lowe and Shaath, 1990; Diffey, pers.comm., 2001)

Skin type	Skin colour (Figure 2.9)	Unexposed buttock skin	Skin reactions to solar radiation	Examples	Minimal erythema (MED)	Painful erythema (MED)	Severe erythema (MED)
I	1	White	Always burns easily and severely, tans little and peels	People most often with fair skin, blue eyes, freckles	0.75	2.25	3.75
II	2, 3	White	Usually burns easily and severely, tans minimally or lightly and peels	People with fair skin, red or blonde hair, blue eyes	1	3	5
III	4	Light brown	Burns moderately and tans about average		1.5	4.5	7.5
IV	5	Moderate brown	Burns minimally, tans easily and above average with each exposure, exhibits immediate pigment darkening reaction	People with white or light brown skin, dark brown hair, dark eyes, e.g. Mediterranean, Orientals	2	6	10
V	6	Dark brown	Rarely burns, tans easily and substantially, always exhibits immediate pigment darkening reaction	People with brown skin, e.g. East Indians, American Indians, Hispanics	-	-	-
VI	7	Black	Never burns and tans profusely, always exhibits immediate pigment darkening reaction	People with black skin, e.g. African and American Negroes, Australian Aborigines	-	-	-

Erythema is typically measured in minimal erythemal dose (MED) units. The MED is used to refer to the EUV dose such that 1 MED is equivalent to an EUV dose of 200 J m^{-2} (Parrish *et al.*, 1982 and CIE, 1997). The MED unit indicates the ultraviolet radiation dose that will elicit an erythemal response of the skin. It can be expressed in J m^{-2} (radiant exposure) or exposure duration (total time in seconds or minutes) for a particular wavelength (Jahan, 1990). One MED is "that amount of ultraviolet radiation

that results in a just perceptible reddening of the skin 24 hours following exposure" (Diffey, 1991: 302).

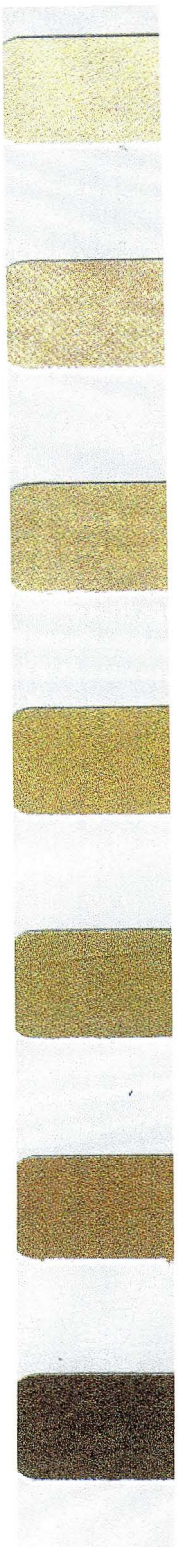


Figure 2.9: Skin colour chart (Courtesy of: Professor B. Martincigh, School of Pure and Applied Chemistry, University of Natal, Durban)

Different skin types may have different MED values such that skin types I, II, III and IV have values of 140, 198, 231 and 261 J m^{-2} respectively (Duigan, 1995). These values are usually standardised for all skin types at 200 J m^{-2}. MED values are thought to depend on age, skin type, pigmentation and the region of the skin, and therefore many photobiologists suggest that a MED value is unique for any given individual (Occupational Health and Safety Series, 1985).

Different parts of the human body also differ in their sensitivity to erythema (Phillips, 1983). Erythema is confined to anatomic sites that are exposed to ultraviolet radiation (Parrish *et al.*, 1978). The head, neck, chest, waist and back are more sensitive than the extremities. Concave surfaces of the limbs are more susceptible to erythema compared to convex surfaces. The least sensitive anatomic sites are the palms and the soles of the feet (Phillips, 1983). Vertical surfaces of an upright person receive approximately 50% of the ambient ultraviolet radiation, while horizontal surfaces such as the shoulder and the vertex of the head receive approximately 75% (Diffey, 1991).

2.3.3.2 Chronic effects of ultraviolet radiation

(a) Photo-ageing of the skin

After prolonged and repetitive exposure to ultraviolet radiation a number of changes occur in the epidermis and dermis of the skin. This is known as 'photo-aged skin' or dermatoheliosis of the skin (Lowe and Shaath, 1990). The appearance of the skin, particularly of light-skinned individuals, due to ultraviolet radiation-induced damage is a result of a decrease in insoluble collagen and an increase in elastin and ground substance (Parrish *et al.*, 1978).

The marked morphologic or visible symptoms of photo-aged skin include wrinkling, dryness, cracking, loss of elasticity, sagging, leathery texture, accentuated skin furrows, mottled or blotchy discolouration and actinic damage (Plate 2.2) (Parrish *et al.*, 1978; Longstreth *et al.*, 1998; NIH, 1989; Lowe and Shaath, 1990 and Diffey, 1991). Pre-cancerous and cancerous skin lesions are also considered components of photo-ageing of the skin (Lowe and Shaath, 1990).

(a) (b)

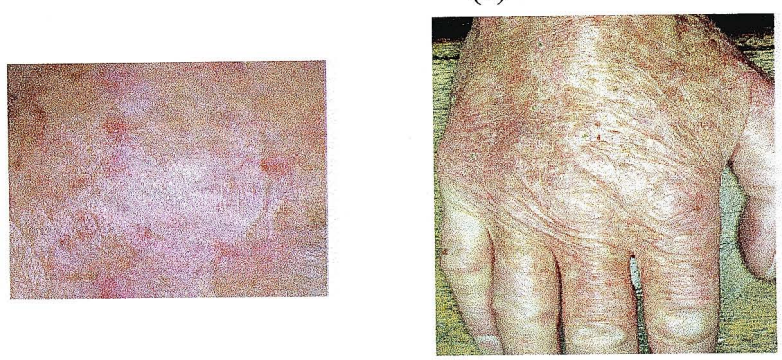


Plate 2.2: Photo-ageing of the skin (a) of the forehead and (b) of the dorsum of the hand (Source: Gawkrodger, 1992: 97)

Diffey (1991) speculated that 80% of the solar ultraviolet radiation-induced photo-ageing occurs within the first 20 years of life except for those circumstances where adult occupation or lifestyle includes extensive ultraviolet radiation exposure periods.

Photo-ageing of the skin is the result of chronic long-term ultraviolet radiation exposure and a selection of risk factors. These include skin colour, melanin pigmentation, ability to repair light-induced damage and genetic susceptibility to actinic damage (Parrish *et al.*, 1978).

The action spectrum for photo-ageing of the skin cannot be readily determined due to the relatively long latency period and slow evolution of the ageing process. However, results from experiments conducted on mice and hairless pigs have been extrapolated for the human condition (Diffey, 1991). Chronic exposure to both UVA and UVB results in physical changes characteristic of photo-ageing (Diffey, 1991). UVA is usually associated with sagging of the skin while UVB is associated with fine wrinkling (Lowe and Shaath, 1990).

(b) Non-melanoma skin cancer

Skin cancer is one of the most common human cancers and there is little dispute that chronic ultraviolet radiation exposure is an important factor in the aetiology of skin

cancer (Diffey, 1991). The argument in support of this relationship between ultraviolet radiation exposure and NMSC is founded on evidence showing that the sites of NMSC are predominantly anatomic sites exposed to ultraviolet radiation and that medium and dark-skinned individuals experience fewer incidences of NMSC. Moreover, it is known that light-skinned outdoor workers and individuals spending time outdoors experience a greater incidence of skin cancer, particularly those living in areas where ultraviolet radiation levels are high (Parrish *et al.*, 1978). The highest rates of NMSC in the past have been recorded in South Africa and Australia (Scotto, 2001).

There are two types of NMSC: squamous cell carcinoma (SCC) and basal cell carcinoma (BCC). SCC is almost entirely attributable to cumulative, chronic ultraviolet radiation exposure (Duigan, 1995) and thus ultraviolet radiation is one of its most important aetiological factors (Conti *et al.*, 1989). It is a tumour that is derived from keratinocytes and usually arises on areas of high ultraviolet radiation exposure or on damaged skin (Gawkrodger, 1992). Damaged sites may include areas of chronic actinic damage, x-irradiation, ulceration, scarring and burns.

The clinical presentation of SCC is on other sites that are frequently exposed to ultraviolet radiation: the face (top of the nose, mucous membrane of the lower lip and forehead), neck, forearm and hand (Pegum and Baker, 1979). The tumour may start within an actinic keratosis, a brownish, hardened area on the skin that is often referred to as a precursor lesion for SCC (Scotto, 2001). SCC begins as a small endophytic growth that progressively invades the dermis and surrounding tissue (Conti *et al.*, 1989). The malignant tumour is also capable of metastasising or multiplying via the lymphatic channels (Pegum and Baker, 1979).

SCC is identified in its early stages as a small nodule or lump that grows rapidly and forms an oval or circular tumour that may be raised a few millimeters above the level of the surrounding skin (Plate 2.3a). The nodule may be red, scaly and develop a crust as it begins to ulcerate (Gawkrodger, 1992). It can progress into a shallow ulcer surrounded by a wide, elevated border (Parrish *et al.*, 1978). SCC is usually treated using surgical excision, skin grafts and radiotherapy such that the entire tumour is removed (Pegum and Baker, 1979).

(a) (b)

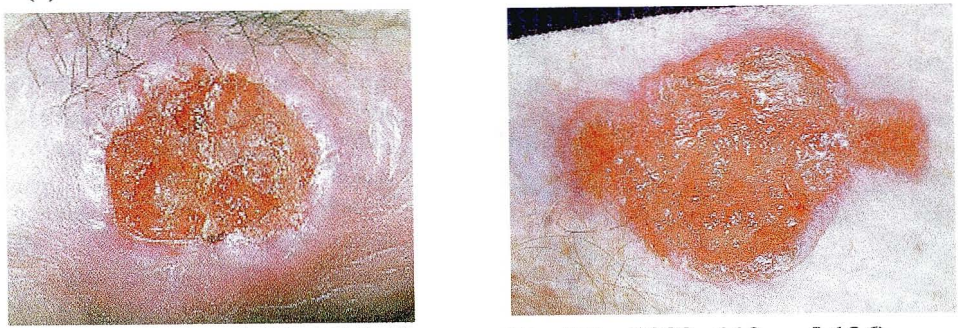


Plate 2.3: (a) SCC and (b) BCC (Source: MacKie, 1989: 119 and 136)

SCC is most common amongst light-skinned males who partake in outdoor occupations and in individuals older than 45 years of age (Pegum and Baker, 1978). The predominant risk factors include fair hair colour, fair skin complexion, difficulty in tanning, tendency to sunburn easily and the presence skin bearing signs of excessive sun exposure in the form of dryness, wrinkling and actinic keratoses (MacKie, 1989). SCC may be lethal but, if treated in its early stages, it is easily removed (MacKie, 1989).

BCC has its origin in the external root sheet of hair follicles in the basal layer of the epidermis and therefore usually arises in areas covered by hair (Conti *et al.*, 1989). It is an epithelial tumour of the skin that is locally invasive but rarely metastasises or spreads extensively (Gawkrodger, 1992). The tumour is composed of uniform basophilic cells in well-defined islands that invade the dermis from the epidermis. The lesion commences as a small, hard painless superficial nodule that, over a period of between 18 months to 3 years, becomes hard, raised and pearly edged with an ulcerous ridge or crust (Plate 2.3b) (Pegum and Baker, 1979). BCC is a slow-growing tumour that usually arises in individuals prior to the age of 40 years and is found predominantly on the temple, nose, eyelid, ear, neck, scalp and back (Gawkrodger, 1992). According to Diffey (1991), 90% of all BCC tumours are found on the head. It appears more frequently in light-skinned males and is associated with ultraviolet radiation exposure as well as on sites of chronic scarring and traumatic injury (MacKie, 1989).

Other risk factors include light hair colour, fair skin complexion, light eye colour, tendency to sunburn easily and extended periods of time spent outdoors (Parrish *et al.*, 1978). The risk of BCC was increased in individuals who reported three or more experiences of painful erythema to an anatomic site in their lifetime (Kricker *et al.*, 1995). However, BCC is not always located on anatomic sites of high ultraviolet radiation exposure. For example, it can occur behind the ear and thus other factors must play a role in its aetiology (MacKie, 1989).

Treatment of BCC is accomplished through the application of radiotherapy or by surgical excision (Gawkrodger, 1992). Often the lesion is present for up to 2 years before the individual seeks medical advice, by which stage the tumour may have already destroyed the surrounding tissue and cartilage and invaded the bone tissue (MacKie, 1989).

Both SCC and BCC are common forms of skin cancer yet have a low fatality rate of less than 1% (Scotto, 2001). BCC tends to be more common, while SCC is more invasive and aggressive and both tend to occur more frequently on exposed anatomic sites. Diffey (1991) suggests that the primary risk factors for contracting NMSC are the amount and nature of solar ultraviolet radiation exposure, age and genetic factors, i.e. phenotypic characteristics, and tendency to sunburn. A geographical latitude relationship also exists such that the incidence of NMSC doubles for every 10□ decrease in latitude, provided the population is 'genetically equally susceptible' (Diffey, 1991).

According to Urbach (1989b), the observed increase in the incidence of NMSC greatly exceeds the expected incidence that is based upon reported stratospheric ozone decreases. Therefore, it would appear that the increases in NMSC are due to factors other than the suggested increase in surface EUV. These may include changes in individual ultraviolet radiation patterns in terms of a more outdoor lifestyle and the wearing of fewer and flimsier clothes. Nevertheless, NMSC incidence rates are increasing and although NMSC is not life threatening in the short-term if treated properly, it can be unsightly and become a burden on an individual's health (Plate 2.4).

(a) (b) (c)

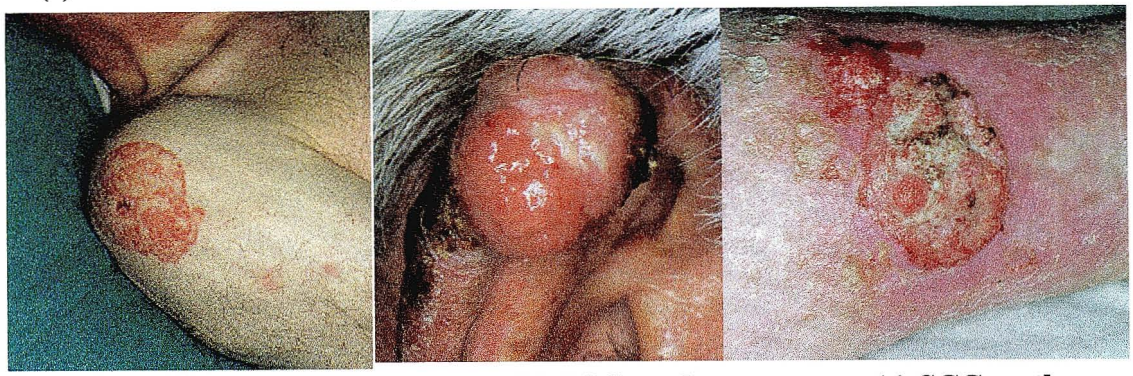


Plate 2.4: (a) BCC on the upper arm, (b) SCC on the upper ear, (c) SCC on the lower leg (Source: Gawkrodger, 1992: 92 - 93)

(c) Malignant melanoma skin cancer

MMSC is a malignant tumour of cutaneous melanocytes that usually arises in the epidermis and is biologically aggressive with the ability to metastasise (Diffey, 1991; Gawkrodger, 1992). In most light-skinned population groups the incidence and mortality rates of MMSC have been rising and are continuing to rise (Conti *et al.*, 1989). The exact causes of MMSC are not certain, however, the major risk factors associated with the development of MMSC are:

- childhood and adult exposure to ultraviolet radiation leading to severe erythema (Longstreth *et al.*, 1998);
- presence of melanocytic and commonly acquired nevi as precursor lesions (Plate 2.5) (Green *et al.*, 1985; Holly *et al.*, 1987 and Conti *et al.*, 1989); and
- phenotypic characteristics such as skin type, eye colour, hair colour and a tendency to experience erythema (Diffey, 1991).

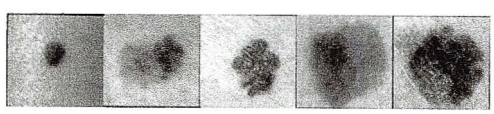


Plate 2.5: Characteristics of nevi in identifying MMSC (a) normal (b) asymmetrical (c) irregular border (d) non-uniform colour (e) continuous increase in diameter (Source: Lapenta, 2001: 1)

MMSC is not always present on anatomic sites that are frequently exposed to ultraviolet radiation or that receive acute intermittent ultraviolet radiation doses, highlighting the fact that ultraviolet radiation is not the single risk factor initiating MMSC (MacKie, 1989). The initial stages of MMSC may be a change in the colour or size of a nevus or the appearance of a new spot on the skin. The spot may have flecks of brown, black, blue or red within it, having an irregular edge that appears to change over a period of a few weeks to months (Gawkrodger, 1992). During the initial stages of its development lasting for several years, the 'spot' grows in a radial, horizontal manner at the junction of the epidermis and dermis (Conti *et al.*, 1989). As the tumour continues to grow, it reaches the next stage of its development growing vertically and metastasising into the dermis (Conti *et al.*, 1989). Early diagnosis and intervention in the initial stage of its development is the only method known to dramatically alter the course of MMSC (Holly *et al.*, 1987) and prohibit it from metastasising widely through the lymph and blood vessels to other organs in the body (Parrish *et al.*, 1978).

There are four clinicopathological subtypes of malignant melanoma: lentigo melanoma, superficial spreading melanoma, nodular melanoma and acral lentiginous melanoma. Each has a different mechanism whereby ultraviolet radiation has its effect (Gallagher, 1986).

Lentigo melanoma develops as a borderline, flat lesion that penetrates the dermis (Conti *et al.*, 1989) and is also known as 'Hutchinson's melanotic freckle' (MacKie, 1989). It is predominantly found on solar ultraviolet radiation exposed and damaged skin, particularly on the face, of individuals over the age of 60 years with a history of cumulative outdoor exposure (Gawkrodger, 1992).

Superficial spreading melanoma is a larger lesion that may be slightly elevated and confined to the epidermis in the initial stage and then extending into the dermis giving rise to nodular lesions (Conti *et al.*, 1989). It accounts for three-quarters of the MMSC found in light-skinned individuals (Conti *et al.*, 1989) and is most common in females (Gawkrodger, 1992). It tends to be located on the lower limbs in females and on the back in males (MacKie, 1989). The lesion has a very irregular outline with pigmentation varying between brown, black and blue. Nodular melanoma develops from a nodule that is raised, blue-black in colour and grows rapidly, appearing

predominantly on the trunk (MacKie, 1989). It is most common in males between the ages of 20 - 60 years of age (Gawkrodger, 1992).

Acral lentigious melanoma begins as a deceptively banal-looking pigmented area and over time becomes a raised and densely black nodular area (MacKie, 1989). It is found on the palms of the hands, soles of the feet, wrists and ankles and in the nail beds (Gawkrodger, 1992). Of the four types, only lentigo melanoma seems to be related to cumulative ultraviolet radiation (Jones, 1987). Acral lentiginous melanoma, superficial spreading melanoma and nodular melanoma may occur in younger individuals and are not confined to chronically sun-damaged areas of the skin (Jones, 1987).

Approximately 75% of MMSC occurs on relatively unexposed anatomic sites (Lee, 1989). The anatomical distribution of MMSC is generally on the lower limbs in women, on the trunk, lower back, scalp and chest of men and on the upper limbs and face of both genders (Plate 2.6) (Conti *et al.*, 1989; Lee, 1989). This may be consistent with a change in clothing and recreational habits adopted by individuals participating in outdoor activities. The anatomic sites tend to be sites that are intermittently exposed to ultraviolet radiation or rarely exposed at all (Gallagher, 1986). MMSC is more common in light-skinned individuals compared to dark-skinned individuals on account of the difference in skin type but may also suggest that natural melanin is a photo-protective mechanism against MMSC (MacKie, 1989).

2.4 Ultraviolet radiation and medium to dark-skinned individuals

Medium and dark-skinned individuals are not immune to the detrimental health effects of exposure to solar ultraviolet radiation. Cases of skin cancer, i.e. NMSC (SCC and BCC) and MMSC, photo-ageing and cataracts (Pathak, 1990) have been evident amongst darker-skinned individuals since the 1940s and 1950s (Shapiro *et al.*, 1953 and Oettle, 1964). Skin cancer remains relatively infrequent amongst these individuals (Shapiro *et al.*, 1953), although Conti *et al.* (1989) state that cataracts are more common in dark-skinned individuals compared to light-skinned individuals.

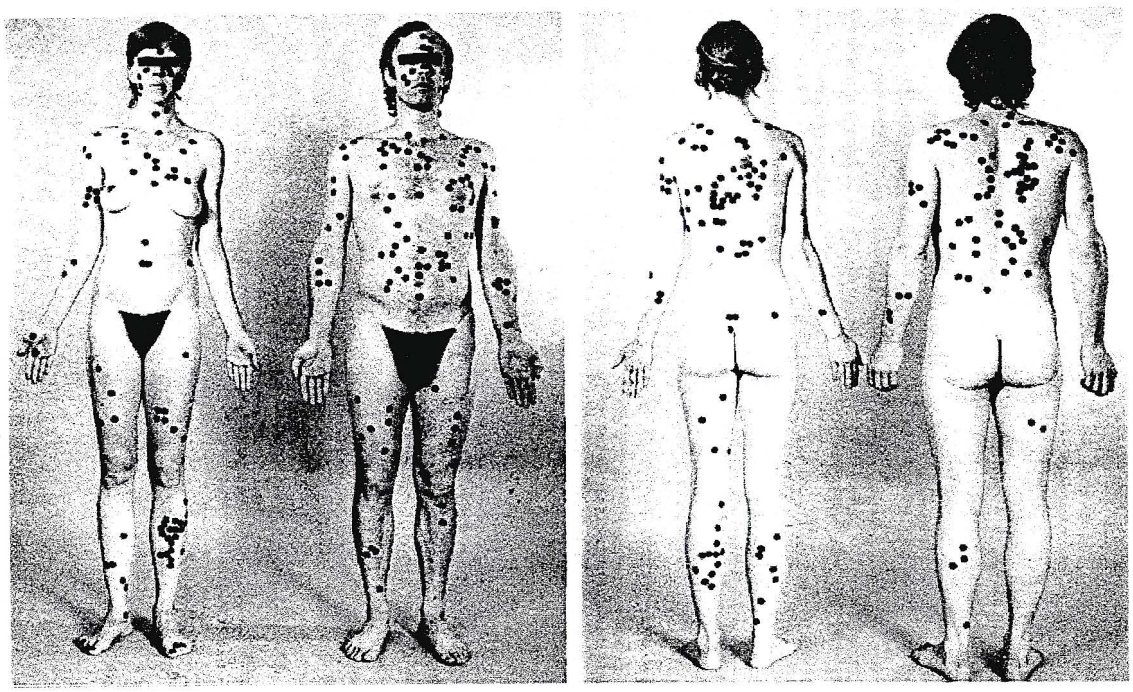


Plate 2.6: Anatomical distribution of MMSC as identified by Harm (1980)

The difference in skin colour is based upon the melanin content of the skin. Both light and dark-skinned people have the same melanin content and the same number of melanocytes per unit surface area (Basset *et al.*, 1986), however, the melanocytes are more active in dark-skinned individuals where they are transmitted to the stratum corneum and stored (Basset *et al.*, 1986). This unique light-absorbing and ultraviolet radiation filtering system provides a front-line defence mechanism. This affords dark-skinned individuals a higher degree of protection from ultraviolet radiation compared to light-skinned individuals and reduces the incidence of skin cancer and skin diseases amongst dark-skinned individuals. However, the lower incidence of skin cancer in these individuals cannot be explained on the basis of racial immunity since medical records show a high incidence of SCC and BCC amongst the African Albino (Shapiro *et al.*, 1953). Therefore, the protective action of pigmentation against sunlight may be the most significant factor in determining the incidence and distribution of skin cancer (Shapiro *et al.*, 1953).

Dark-skinned individuals have a distinct anatomical distribution of skin cancer appearing predominantly on the lower extremities and on sites of long-standing chronic infections, scars, burns, wounds and ulcers (Malik *et al.*, 1974). Figure 2.10 illustrates the typical anatomical distribution of three skin cancers, SCC, BCC and

MMSC amongst dark-skinned individuals where the shading illustrates frequently exposed anatomic sites. It would appear that areas of ultraviolet radiation exposure are less common sites for the development of skin cancer compared to areas of chronic irritation (Shapiro *et al.*, 1953).

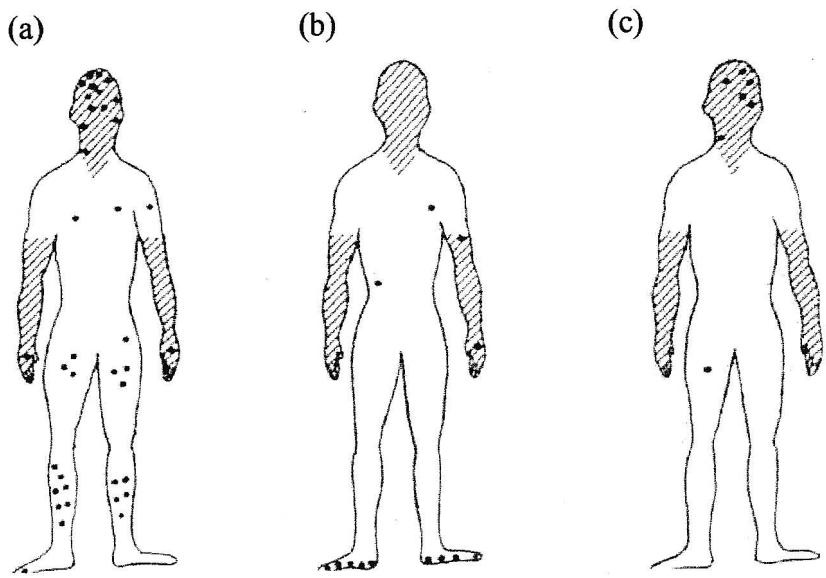


Figure 2.10: Anatomical distribution of (a) SCC, (b) MMSC, and (c) BCC in dark-skinned individuals where shaded areas indicate anatomic sites frequently exposed to sunlight (Adapted from: Fleming *et al.*, 1975: 601)

According to Oettle (1964), the major factors in the development of skin carcinoma are solar exposure and pre-existing chronic skin irritations. Fleming *et al.* (1975) saw that MMSC in dark-skinned individuals tended to present itself on the plantar region (sole) of the foot, often on an existing nevus. Shapiro *et al.* (1953) support this argument stating that melanin pigmentation does play a protective role against ultraviolet radiation, however, under the stress of chronic processes that cause ulcers or wounds, any portion of the body may be affected and lead to the occurrence of any one of the skin cancers.

A study conducted by Fleming *et al.* (1974) noted that of 58 cases of skin cancer amongst dark-skinned individuals, 38 were SCC, 13 were MMSC and 7 were BCC. Of the 38 cases of SCC, 61% developed on unexposed anatomic sites and 41% developed as a complication of a tropical ulcer, wound, scar, burn or other chronic infection. SCC

was identified as an aggressive disease amongst dark-skinned individuals, invading the bone and resulting in amputation of the infected anatomic site (Basset *et al.*, 1986). The common sites of SCC include the head and neck (Malik *et al.*, 1974), the lower extremities, i.e. calves and feet, and the lower lip. In North Africa, Basset *et al.* (1986) observed cases of SCC on the scalp as a combination of solar exposure and the wearing of turbans and other headgear containing carcinogenic aniline dyes.

Shapiro *et al.* (1953) recognised a gender-related difference in the incidence of SCC, with a higher incidence amongst males. Malik *et al.* (1974) also noted a gender-related difference in the incidence of SCC, with males being higher than females. This was explained as reflecting the outdoor nature of the male lifestyle. The average age for diagnosis of SCC was noted as 59 years and ranged from 17 - 75 years (Malik *et al.*, 1974).

African Albinos who are exposed to ultraviolet radiation have been reported to have an increased incidence of SCC and BCC on exposed anatomic sites (Fleming *et al.*, 1974). Due to a reduced amount of dermal melanin pigmentation, Albinos are more susceptible to developing SCC and BCC and there is a tendency for it to develop at an early age (Oettle, 1964). Plate 2.7 shows a well-developed SCC on the left cheek having invaded the eyelid and left eye. Albinism is considered to be an important factor when considering the risk of skin cancer amongst dark-skinned individuals (Fleming *et al.*, 1974).

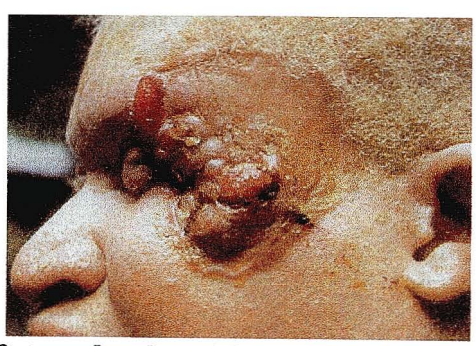


Plate 2.7: SCC on the left temple of an African Albino (Source: Basset *et al.*, 1986: 95)

MMSC is described as being less common amongst dark-skinned individuals compared with light-skinned individuals (Conti *et al.*, 1989). Opinion varies with

regard to the intensity of the disease, with Fleming *et al.* (1974) describing MMSC as a 'virulent tumour' in dark-skinned individuals and Shapiro *et al.* (1953) commenting that MMSC tended to develop as a less potent disease amongst dark-skinned individuals, remaining localised to the lymphatic system.

The anatomical distribution of MMSC occurs predominantly on 5 sites: palms of the hands, soles of the feet, heels, under the fingernails and in the mouth (Pathak, 1990). MMSC in dark-skinned individuals is often present on the sole of the foot where it may develop on a nevus during puberty and represent a pre-malignant lesion. This may then develop into MMSC during adulthood following repeated trauma to the site and cumulative ultraviolet radiation exposure to other parts of the body (Fleming *et al.*, 1974).

The deleterious health effects of ultraviolet radiation exposure on dark-skinned individuals extend beyond skin cancer to include cataracts, photo-ageing and immuno-suppression. Corticol cataracts are significantly more common amongst dark-skinned individuals than light-skinned individuals, even though exposure to ultraviolet radiation may not differ between the two groups (EHP, 1998). Cumulative exposure to ultraviolet radiation increases the risk of the development of cataracts. A study undertaken by the National Institute on Ageing demonstrated a significant difference in the risk of cataracts among dark and light-skinned individuals even after testing for factors such as alcohol use, education, smoking, eye colour, hypertension and diabetes (EHP, 1998). Oettle (1964) noted that there was also a high frequency of SCC of the conjunctiva amongst dark-skinned individuals that was attributable to ultraviolet radiation exposure.

2.5 Childhood ultraviolet radiation exposure and the risk of skin cancer

Solar ultraviolet radiation exposure in early childhood is believed to be particularly important in determining the future risk of skin cancer, for both non-melanoma skin cancer (NMSC) and malignant melanoma skin cancer (MMSC) during adulthood. This is founded upon the recognition that ultraviolet radiation-induced damage of the skin is one of the causes of skin cancer (Weinstock *et al.*, 1989). A number of studies have based their research upon this hypothesis, linking childhood ultraviolet radiation

exposure with the development of skin cancer during adulthood. These include Lew and Rosenthal (1988), Diffey *et al.* (1996), Gies *et al.* (1998), Moise *et al.* (1999a), Moise *et al.* (1999b), O'Riordan *et al.* (2000), and Kimlin and Parisi (2000).

Moise *et al.* (1999b) state that there is evidence to show that solar exposure during childhood and adolescence, especially between the ages of 6 - 18 years, or before the age of 20 years plays an important role in the aetiology of skin cancer. Truhan (1991) notes that childhood is a particularly vulnerable period for the subsequent photocarcinogenic effects of ultraviolet radiation on human skin. A typical South African child of school-going age spends approximately 195 days attending school and the remaining at their leisure, consequently receiving a substantial portion of their lifetime ultraviolet radiation dose during their early years (Moise *et al.*, 1999a). Both intermittent and cumulative solar ultraviolet radiation exposure patterns are shown as important risk factors for skin cancer, while various epidemiological studies emphasise the role of childhood ultraviolet radiation exposure in accentuating the risk of contracting skin cancer, both NMSC and MMSC, during adulthood (Diffey *et al.*, 1996).

2.5.1 Initial findings

The hypothesis outlining the relationship between childhood exposure to solar ultraviolet radiation and an increased risk of skin cancer during adulthood was derived from case-control studies and other research conducted during the 1980s. Weinstock *et al.* (1989) state that the hypothesis emerged from studies of intercontinental migration. These studies observed a common trend. People originating from countries with relatively low surface ultraviolet radiation levels and who immigrated after the age of 20 to a country with higher surface ultraviolet radiation levels, showed a very low incidence of MMSC compared to the inhabitants of the country of migration of the same age, but having resided there for their entire lifetime (Marks *et al.*, 1990). Thus, there was a decreased risk for migrants to sunny climates contracting skin cancer during adulthood compared with the native inhabitants of that area.

Marks *et al.* (1990) describe the results of a study that aimed to determine the role of exposure to ultraviolet radiation during childhood in the development of actinic

keratoses and by inference, SCC, which were seen in members of the Australian population at the time of the study. The study showed that British people of any age who immigrated to Australia had a lower incidence of SCC and MMSC than those people who arrived before the age of 19 years, in spite of spending subsequent years in Australia. Thus, children growing up in Australia had a higher risk of contracting SCC than British adults who immigrated to Australia. Moreover, the British immigrants to Australia experienced a lower incidence rate of solar keratoses and associated tumours, including SCC, seen in Australians of the same age, highlighting the importance of ultraviolet radiation exposure during childhood in increasing the risk of skin cancer and associated skin diseases (Marks *et al.*, 1990).

Lee (1989) supports these findings by stating that people who were born in Europe and migrate to Australia have lower incidence rates of skin cancer compared with people of European decent born in Australia, providing that the immigrants do not immigrate as children. Truhan (1991) describes how migration to sunnier climates during childhood increases the risk of skin cancer amongst children who experience painful and severe erythema where the tendency to sunburn easily is the critical risk factor rather than the number of sunburns.

A case-control study focusing on women conducted in Massachusetts (USA) examined the relationship between the timing of severe ultraviolet radiation exposure and the incidence of MMSC (Weinstock *et al.*, 1989). The subjects were female, aged between 38 - 65 years, with no history of MMSC in their first-degree relatives and all diagnosed as having MMSC. The hypothesis was that blistering sunburns between the ages of 15 - 20 years were associated with a high risk of contracting MMSC. All of the subjects were interviewed and the average number of severe, blistering sunburns of all the subjects was between 2 - 9 for ages 15 - 20 years (Weinstock *et al.*, 1989).

2.5.2 The hypotheses

Emerging from these initial findings are two candidate hypotheses: one emphasising the role of excessive ultraviolet radiation exposure during childhood and the other emphasising the role of intermittent ultraviolet radiation exposure throughout one's lifetime, both in relation to the risk of contracting skin cancer. Osterlind *et al.* (1988)

suggest that there is a clear association between MMSC and multiple painful sunburns before the age of 15 years, while no significant association exists for sunburn events occurring during early adulthood (16 - 24 years). Thus, a high risk factor exists in terms of painful sunburns experienced during childhood, consistent with the hypothesis that the important time of intense ultraviolet radiation exposure may be in early life (Lee, 1989). However, Weinstock *et al.* (1989) point out that the malignant disease follows a multi-stage time-dependent process passing through critical stages such as in early childhood, that increase the chances of completing the remaining stages of carcinogenesis in later years and increasing the risk.

Evidence suggests that the timing of intense ultraviolet radiation exposure in accentuating the risk of skin cancer is age-specific (Marks *et al.*, 1990), where ultraviolet radiation exposure during childhood may be only one important risk factor. Intermittent ultraviolet radiation exposure during adulthood such as during vacations and recreational activities provides for acute, intense ultraviolet radiation exposure periods that may result in severe sunburn and subsequently an increased risk of skin cancer (MacKie and Aitchison, 1982; Sorahan and Grimley, 1985 and Conti *et al.*, 1989).

Acknowledgement of a link between timing of solar ultraviolet radiation exposure during childhood, adolescence and again in early adult life and a delay in the occurrence of MMSC has been expressed in terms of a multistage model of carcinogenesis or tumour formation (Stern *et al.*, 1986). There are five stages of carcinogenesis ranging from stage 0 to stage 5, where no disease is present at stage 0 and a tumour appears at stage 5. The transition from one stage to the next is dependent on the ultraviolet radiation dose and timing of exposure (Stern *et al.*, 1986). In this five-stage process, stage 1 and stage 4 are dose-dependent stages, the first being during childhood and the second during adulthood. Therefore, high levels of ultraviolet radiation exposure during childhood will have laid the foundation for triggering the transition to stage 4 and then to the development of cancer, even if exposure in stage 4 during adulthood is relatively lower than during childhood. Thus, childhood and adult ultraviolet radiation exposure periods act interdependently (Longstreth *et al.*, 1998).

Holman *et al.* (1986) state that intermittent exposure to ultraviolet radiation, in early adult life, particularly during the ages of 15 - 24 years, appeared to be most important in association with the superficial spreading of MMSC during adulthood. This period of ultraviolet radiation exposure during early adulthood posed more of a risk to the contracting of cancer than exposure prior to age 40 years or even 10 years before the diagnosis of MMSC (Holman *et al*, 1986). Osterlind *et al.* (1988) suggest that these occasional intense periods of ultraviolet radiation exposure during adulthood posed a higher risk factor, particularly for MMSC, while continuous outdoor, occupational ultraviolet radiation exposure had no effect in increasing the risk of MMSC.

An individual's history of experiencing erythema has been associated with the risk of skin cancer (MacKie and Aitchison, 1982) where severe and frequent occurrences of erythema conferred a high risk factor (Elwood *et al.*, 1990). Elwood *et al.* (1984) consider this to include erythema during childhood, erythema whilst on vacation during adulthood and erythema during recreational activities during adulthood. Dubin *et al.* (1990) point out that a history of severe, blistering sunburns was associated with a 60% increase in the risk of MMSC and an 80% increase in the risk of NMSC.

Therefore, the two pertinent arguments are that ultraviolet radiation exposure during childhood is the fundamental risk factor and that intense intermittent ultraviolet radiation exposure during adulthood increases the risk (Conti *et al.*, 1989). Table 2.4 summarises the ages, suggested by various authors, when the occurrence of severe erythema, or blistering sunburn, was most likely to increase an individual's risk of contracting skin cancer during adulthood. A number of inherent discrepancies exist with the association between ultraviolet radiation exposure and the development of skin cancer. Multiple erythema incidents appear to play a vital role in both arguments.

However, the link between erythema events and the risk of developing skin cancer is contentious, particularly when attempting to ascertain the number of times erythema was experienced during childhood in a retrospective study that relies on an individual's memory. Often people tend to remember severe erythema incidents until a certain age, beyond which memories become blurred. Moreover, it is not always possible to find a link between the site of the severe erythema and the site of the cancerous skin tumour (Conti *et al.*, 1989). Clearly it is evident that the epidemiological features of skin

cancer exhibit a complex relationship with ultraviolet radiation and cannot simply be justified by one single risk factor such as childhood ultraviolet radiation exposure, although this risk factor does appear to play an important role in influencing that risk.

Table 2.4: Summary of ages identified by various authors when severe erythema events are most likely to increase the risk of skin cancer during adulthood

Author	Identified age
Holman *et al.* (1986)	15 – 24 years
Osterlind *et al.* (1988)	< 15 years
Weinstock *et al.* (1989)	15 – 20 years
Elwood *et al.* (1990)	8 – 12 years
Moise *et al.* (1999b)	6 – 18 years

According to Weinstock *et al.* (1989), blistering erythema during adolescence may be more intense compared to erythema incidences later in life due to the nature of adolescent behaviour patterns. Societal norms in fashion dictate that a 'suntan' in a fair-skinned individual is associated with increased socio-economic status, health, vibrancy and self-confidence (Marks *et al.*, 1990). Both children and adolescents have many more summer days available to them compared to adults (Truhan, 1991), spending time outdoors engaged in activities such as swimming. In sunny and warm weather, fewer clothes are worn, increasing the amount of exposed skin and the potential EUV dose received.

2.5.3 Risk factors

The nature and magnitude of an individual's ultraviolet radiation dose is not the only risk factor in terms of skin cancer. Associated risk factors include total number and nature of nevi, susceptibility to sunburn, skin type and colour, and family history of skin cancer (Diffey, 1991). According to Lee (1989), the lifetime risk of MMSC for an individual is established by the age of 20 years, thereby emphasising the role of childhood ultraviolet radiation exposure. Thereafter, the risk increases relative to one's age and ultraviolet radiation exposure patterns.

Other risk factors for MMSC include hair colour, eye colour, freckling during adolescence (Elwood *et al.*, 1984), an individual's usual skin reaction to one-hour exposure to the first summer sun and the depth of the tan after repeated ultraviolet radiation exposure (Weinstock *et al.*, 1989). Conti *et al.* (1989) identified the ambient ultraviolet radiation levels characteristic of an individual's place of residence and their exposure habits as risk factors, where cumulative exposure during childhood and acute intermittent exposure during adulthood accentuated the risk of skin cancer.

A threshold effect of 2 severe sunburns was deduced as a fundamental risk factor of contracting MMSC (Weinstock *et al.*, 1989). Other factors, for example skin sensitivity and latitude of residence during adolescence, are also thought to play a vital role in the risk of MMSC. Ultraviolet radiation exposure during adolescence was presented as a more important potential determinant of MMSC incidence than ultraviolet radiation exposure after the age of 30 years (Weinstock *et al.*, 1989).

In terms of NMSC, risk factors other than ultraviolet radiation exposure during childhood include light skin colour, a family history of skin cancer and precursor lesions (Truhan, 1991). The development of nevi, during childhood and adolescence, is also one of the risk factors of skin cancer. Holman *et al.* (1986) outline the typical progression of nevi as appearing during adolescence and gradually being eliminated from the skin during adulthood. A critical period in the development of a nevus is its promotion to a more complex form, i.e. MMSC due to ultraviolet radiation exposure. If it is not 'promoted' by ultraviolet radiation exposure, its expected course is either to regress or mature into an intradermal, benign nevus (Holman *et al.*, 1986).

Of all the risk factors for both NMSC and MMSC, ultraviolet radiation exposure is the only risk factor that is avoidable. Stern *et al.* (1986) calculated that by using a sunscreen with a sun protection factor of 15 during childhood and adolescence, it would potentially reduce the lifetime incidence of MMSC by 78%. By applying sunscreen to the face, neck, upper chest and arms each summer day during the first 18 years of one's life, the risk of skin cancer, photo-ageing of the skin and erythema could be reduced (Stern *et al.*, 1986).

There is clearly a link between childhood ultraviolet radiation exposure and the risk of skin cancer during adulthood. This study will investigate the ultraviolet radiation exposure of children and adolescents between the ages of 4 - 14 years in order to assess this risk and provide recommendations for preventing the incidence of adverse health impacts as a result of exposure to ultraviolet radiation. The following chapter describes the methodology employed in measuring the ultraviolet radiation doses of children and adolescents in Durban, as well as the quantification of the anatomical distribution of ultraviolet radiation using a mannequin.

Chapter Three
METHODOLOGY

3.1 Introduction

This study makes use of data extracted from three primary sources: the employment of polysulphone film badges (PSFBs) as ultraviolet radiation dosimeters, personal ultraviolet radiation exposure journals and ambient erythemal ultraviolet radiation (EUV) measurements recorded by a YES UVB-1 pyranometer. These data sets were then utilised to compute the daily EUV doses and exposure patterns of children and adolescents; the comparison of the daily EUV doses and exposure patterns of children and adolescents with the ambient EUV incident upon the earth's surface and to investigate the anatomical distribution of ultraviolet radiation under clear and overcast conditions.

3.2 The polysulphone film dosimeter

Polysulphone film (PSF) was first identified as a reliable means of measuring a person's solar ultraviolet radiation dose in 1976. This finding originated from an evaluation of the weathering characteristics of the plastics polysulphone and polyphenylene oxide, both of which were found to darken when exposed to ultraviolet radiation from the sun. Davis *et al.* (1976) then realised the potential of the polymer, polysulphone, as a personal ultraviolet radiation dosimeter.

There are three types of ultraviolet radiation dosimeters: biological, chemical and physical dosimeters (Diffey, 1990). The thermoplastic polysulphone is not a true biological dosimeter, however, it mimics the erythemal action spectrum (Webb, 1995) thereby measuring energy, compared to physical devices that measure power (Diffey, 1990). PSF is thus a passive dosimeter that possesses a spectral response approximating the human erythemal response (Wong and Parisi, 1999) and is commonly used to quantify the EUV dose of individuals.

Structurally, polysulphone is a typical polymer that consists of large molecules made up of repeating subunits (Figure 3.1). The technique of making PSF entails the use of a specifically designed table to ensure the production of consistent and reproducible sheets of film. Polysulphone in soluble form is cast onto the glass top of the casting table and smoothed over to become optically flat at a particular height using a motorized blade. The height of the blade is adjustable to produce the required thickness of the film (Parisi *et al.*, 2000a).

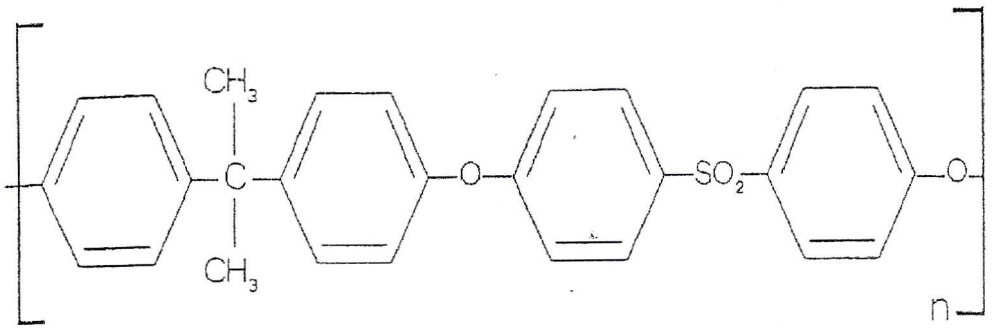


Figure 3.1: Chemical structure of the polysulphone monomer (Adapted from: Davis *et al.*, 1976: 16)

The thickness of PSF may vary amongst manufacturers, reaching up to 50 μm (Parisi *et al.*, 2000a). The dose-response of PSF is highly dependent upon film thickness and film of the same thickness should be utilised in one particular study. Generally, PSF between 40 - 50 μm thick is employed as a compromise between the need for easy handling and approximating the human erythemal action spectrum (Parisi *et al.*, 2000a). The PSF utilised in this study was 50 μm thick, cast by Complas LTD in the United Kingdom and was prepared based on the technique employed by Davis *et al.* (1976) through the re-precipitation of polysulphone crystals in solution.

The principal motivation for using PSF as an ultraviolet radiation dosimeter is that the photosensitive film degrades when irradiated by ultraviolet radiation. By measuring the change in absorbance of the film at 330 nm (ΔA_{330}) following ultraviolet radiation exposure, the degree of degradation may be quantified in terms of the EUV dose. Pre- and post-exposure absorbance measurements of the film may be completed using a standard ultraviolet spectrophotometer. The ultraviolet radiation-induced 'deterioration' of the film is then calibrated against simultaneous EUV measurements

recorded by a physical meteorological instrument (Parisi *et al.*, 2000a). A dose-response curve may be determined and the EUV dose of the film may be calculated.

PSF dosimeters have been used extensively to measure personal ultraviolet radiation doses. Their popularity in scientific research is founded upon the advantages of using the film. These include:

- The spectral sensitivities of PSF are similar to photobiological responses (Horneck, 1995).
- PSF is not affected by temperature (Webb, 1995).
- PSF readily undergoes changes in surface properties when exposed to ultraviolet radiation (Davis *et al.*, 1976).
- PSF can be minatuarised to form a simple badge that requires no power and is sufficiently small and versatile to be attached to a variety of surfaces (Webb, 1995).
- The PSFB is an economical means of quantifying a large range of individuals' EUV doses (Horneck, 1995).
- PSF is waterproof and can therefore be used in water sports, e.g. swimming (Webb, 1995) as long as the PSF mounting is waterproof.

There are three limitations to employing PSF as a personal ultraviolet radiation dosimeter:

- The use of PSF does not permit an assessment of the magnitude and change in exposure rate during the measurement period and therefore simply provides a cumulative EUV dose (Diffey and Saunders, 1995).
- The film's sensitivity extends up to wavelengths of 330 nm whereas the biological effectiveness of UVB is confined to the wavelength range of 280 - 320 nm (Diffey, 1986).
- The pre- and post-exposure absorbance measurements of PSFBs are labour-intensive. Depending upon the dexterity of the operator, the process requires between 5 - 10 seconds per badge.

Despite these limitations, PSF may be used to quantify an individual's ultraviolet radiation dose and to relate these results to ambient ultraviolet radiation levels monitored by land-based instrumentation.

3.3 Ambient ultraviolet radiation measurements in Durban

The continuous monitoring of ambient UVB and EUV in Durban was first initiated in 1993 by the Physics Department (University of Natal, Durban) with the acquisition of a Yankee Environmental Systems (YES) UVB-1 pyranometer (Duigan, 1995). A UVB-1 pyranometer is a precision meteorological instrument that measures global solar ultraviolet irradiance (Plate 3.1). These instruments are used at a number of ultraviolet radiation monitoring stations around the world. The instrument uses one voltage signal and applies different conversion factors to derive UVA, UVB and EUV measurements. A digital logger then continuously records these ultraviolet radiation measurements at 10-minute time intervals.

Plate 3.1: A typical UVB-1 pyranometer

The YES UVB-1 pyranometer is situated on the roof of the Desmond Clarence building in a un-shaded location and horizontally oriented manner (Plate 3.2). Data measured by the YES UVB-1 pyranometer were used for the calibration of the PSF as well as providing the ambient EUV conditions during various components of the various study periods.

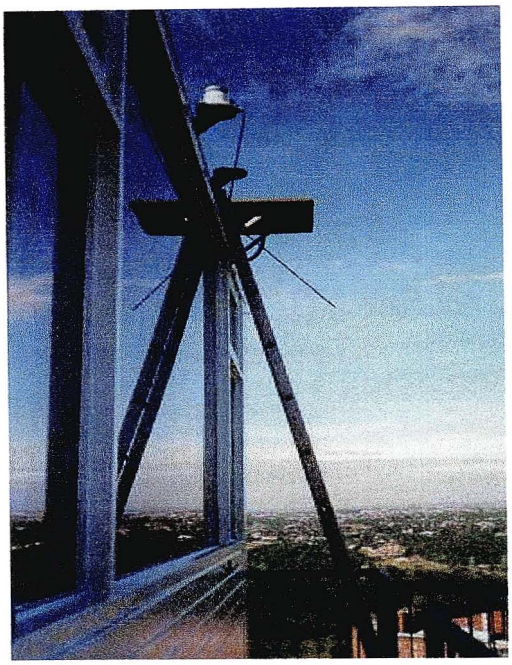


Plate 3.2: Location of the YES UVB-1 pyranometer on the roof of the Desmond Clarence building, University of Natal (Durban)

3.3.1 General description of the YES UVB-1 pyranometer

The YES UVB-1 pyranometer is one variation of the Robertson-Berger meter that first originated in Australia in the late 1950s (Diffey, 1991). The Robertson-Berger meter was built in response to the need for an instrument that was able to record solar ultraviolet radiation incident upon a horizontal surface at the earth's surface. The monitoring system was required to have a spectral response that approximated the erythemal action spectrum of human skin. The instrument fulfilled these requirements and has consequently been used extensively to measure integrated ultraviolet radiation in the waveband 280 - 320 nm.

Ultraviolet-calculating solar dose modeling software is included with the YES UVB-1 pyranometer. This programme uses a sophisticated ultraviolet radiation transmission model to calculate surface ultraviolet irradiance as a function of ozone column height and aerosol density. The instrument is small and compact making it ideal for continuous monitoring without the need for constant supervision and maintenance. It is internally temperature-stabilised to ensure the accuracy of its measurements in all weather conditions (Instruction Manual: Model UV-B-1 ultraviolet pyranometer).

3.3.2 Operation principles of the YES UVB-1 pyranometer

The YES UVB-1 pyranometer consists of coloured glass filters and a UVB sensitive phosphor. It uses fluorescent phosphor to convert the UVB light to visible light and this in turn is measured by a solid-state photodiode (Instruction Manual: Model UV-B-1 ultraviolet pyranometer). Figure 3.2 shows the light entering the instrument via a coloured glass ultraviolet band filter or an ultraviolet-transmitting weather dome, as in the case of the YES UVB-1 pyranometer used at the University of Natal (Durban).

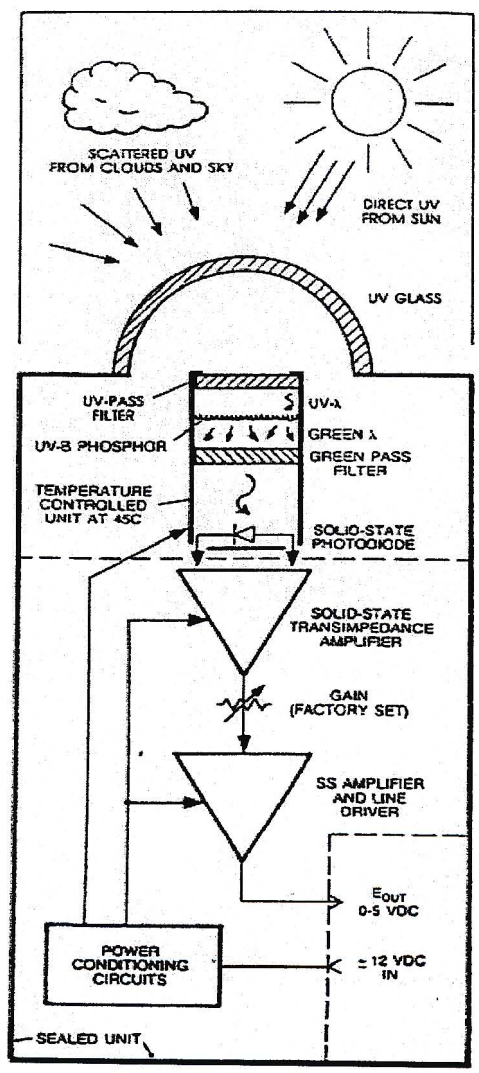


Figure 3.2: A diagrammatic sketch of the operation principles of the YES UVB-1 pyranometer (Source: Instruction Manual: Model UV-B-1 ultraviolet pyranometer)

The transmission curve of this filter is similar in shape to the Diffey erythemal action spectrum, also known as the CIE reference action spectrum (Prause *et al.*, 1999). The first ultraviolet-pass filter consisting of black glass absorbs all of the visible light except for a small proportion of red light. The light that passes through this filter then strikes the UVB sensitive phosphor that absorbs ultraviolet radiation and re-emits it as visible green light. The fluorescent light then passes through a green pass filter and a solid-state photodiode or photodetector that measures the intensity of the light. This is converted to a voltage signal and recorded by a digital logger that automatically stores a reading at 10-minute intervals.

3.3.3 Data processing and interpretation

The YES UVB-1 pyranometer uses the one voltage signal to derive all the required information for two ultraviolet irradiances including:

1. Ultraviolet irradiance in the waveband 280 - 320 nm
2. Erythemal irradiance weighted by the Diffey action spectrum (280 - 320 nm)

The calculation of these irradiances is accomplished through the application of different conversion factors supplied by the manufacturer. The conversion factor is defined as the ratio of energy measured by the detector with an ideal cosine and spectral response to the energy measured by the YES UVB-1 pyranometer (Instruction Manual: Model UV-B-1 ultraviolet pyranometer). Finally, using a correction factor that depends on the solar zenith angle at the time of the measurement completes the correction of the voltage signals to the respective irradiances as follows:

$$E_i = K_i\,(SZA) \times V \qquad (3.1)$$

where V is the raw voltage recorded and K_i (SZA) is the correction factor for type 'i' ultraviolet radiation. Furthermore, i may be integrated ultraviolet irradiance (280 - 320 nm) or erythemal irradiance weighted by the Diffey action spectrum (280 - 320 nm) and E_i the type 'i' ultraviolet irradiance (W m^{-2}). These conversion and correction

factors allow for the calculation of the desired irradiance using the single voltage measured by the YES UVB-1 pyranometer.

3.3.4 Data utilisation

The irradiance weighted by the Diffey action spectrum for the waveband 280 - 320 nm was used to illustrate the ambient EUV for Durban. It was also used in the calibration of the PSF since they both correspond with the erythemal action spectrum (Davis *et al.*, 1979). EUV is derived from solar irradiance weighted by the erythemal action spectrum, indicated in Figure 3.3. Personal ultraviolet radiation dosimetry studies employing PSF measure the change in absorbance of the film at 330 nm as this wavelength is proportional to the erythemal action spectrum proposed by the CIE (Diffey *et al.*, 1976, and CIE, 1987). As PSF degrades, the initial broad absorption band in the near ultraviolet moves towards the visible end of the spectrum. Since 330 nm is in the transition region between these two parts of the spectrum, measurement at this wavelength provides a link between polysulphone degradation and the incident EUV dose (Diffey, 1986).

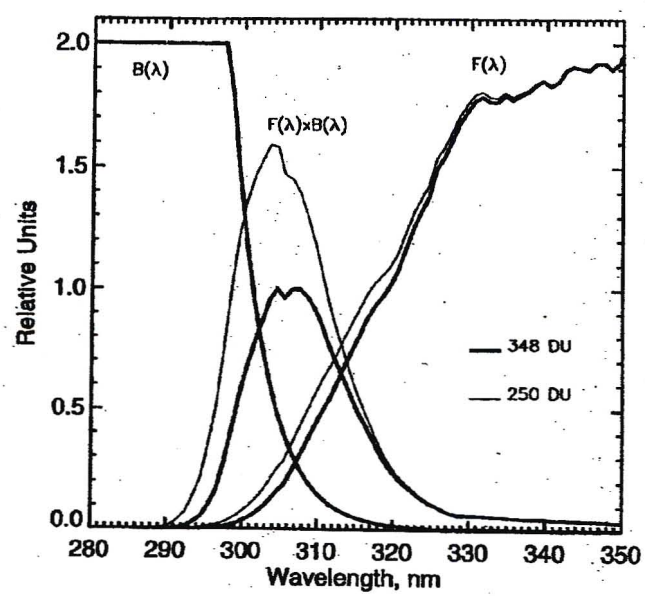


Figure 3.3: Overlap between spectral irradiance *F* ( ) and the erythemal action spectrum *B* ( ) shows the spectrum of biologically effective EUV, *B* x *F*. Thick lines are for a total ozone column of 384 DU and thin lines for an ozone column of 250 DU (Source: Zerefos and Bais, 1995: 35)

Making use of the Diffey weighted YES UVB-1 pyranometer EUV allowed for the comparison of the surface EUV levels with the PSFB doses of the subjects. It was assumed that the surface EUV recorded by the YES UVB-1 pyranometer was representative of the ambient EUV conditions for full coverage of the study area including the four schools and surrounding environs. Cloudy periods or days were not removed from the data recorded by the YES UVB-1 pyranometer.

In certain instances, EUV was converted into minimal erythemal dose units (MED). MED units have been used throughout this study where 1 MED unit = 200 J m^{-2}. These values were in accordance with international standards and similar studies (Diffey *et al.*, 1996; CIE, 1997).

3.3.5 Errors and assumptions

The data obtained from the YES UVB-1 pyranometer were received in a processed format and had already been converted to EUV (280 - 320 nm). Data processing also entailed the subtraction of the dark current or the voltage occasionally recorded by the YES UVB-1 pyranometer during conditions of nil exposure. The overall percentage of data availability was 99% as there was only one day of complete data loss due to instrument interference.

There are various inherent errors in using the YES UVB-1 pyranometer. The cosine error is responsible for the deviation of light incident at an acute angle and the second error is made when the conversion factors are estimated for a certain solar angle at a particular solar zenith angle (Prause *et al.*, 1999). Broadband instruments such as the YES UVB-1 pyranometer are also influenced by total column ozone thickness where wavelength mismatches need to be corrected for. For detail, see Bodhaine *et al.* (1998). To avoid inaccuracy, the manufacturer calibrates the YES UVB-1 pyranometer with respect to wavelength and absolute intensity and manual checks are performed at noon on a daily basis. The YES UVB-1 pyranometer housed at the University of Natal (Durban) was last compared to a secondary calibration source in 1999, where this secondary calibration source had been calibrated in late 1998 (Diab, 2000).

Two assumptions are inherent in the YES UVB-1 pyranometer data processing phase. It is assumed that the spectral distribution of the light incident upon the ultraviolet radiation-transmitting dome remains constant and that any changes in the ratio between variables would not be evident in the results following conversion from the original voltage signal. According to Duigan (1995), the absolute accuracy of the surface ultraviolet radiation measurements is limited to 5% since the ultraviolet band constitutes less than 10% of the electromagnetic spectrum.

3.4 Calibration procedures for polysulphone film

In order to determine the EUV dose of PSF, the film must be calibrated against another ultraviolet radiation-measuring instrument. For the purpose of this study calibration of the PSF was based on broadband ultraviolet radiation measurements made by the YES UVB-1 pyranometer located on the roof of the Desmond Clarence building.

The calibration procedure entailed the use of PSF strips with dimensions of 1 cm by 4 cm, each tagged with masking tape on one end allowing for handling without physical contact with the film. Each strip was stored in its own light-impervious envelope. All absorbance measurements were made using a Varian DMS 300 UV-Visible spectrophotometer located in the School of Pure and Applied Chemistry at the University of Natal (Durban). The spectrophotometer was zeroed against air before both the pre- and post- exposure measurements for all PSF strips and PSFBs. The pre-exposure absorbance measurements at 330 nm of each strip used in the calibration procedure ranged between 0.133 and 0.286 absorbance units (A) (Appendix I; Table 1).

Exposure of the PSF strips to ultraviolet radiation took place over a period of four days. The exposure times used in the calibration procedure are presented in Table 3.1. On each day, all the respective PSF strips for that particular exposure period were attached to a piece of transparent perspex (28 cm by 5 cm) and placed in an un-shaded location approximately 0.5 m from the YES UVB-1 pyranometer and on the same horizontal plane.

Each PSF strip was exposed for a predetermined period ranging from five min to 8 hrs such that cumulative EUV doses were measured and the final strip received the highest EUV dose. As each PSF strip was removed from the perspex sheet, it was placed in its original envelope and stored until the following day. The post-exposure absorbance measurements were completed 24 hours after the removal of the final PSF strip and are presented in Appendix I (Table 1). The change in absorbance for each strip was calculated as follows (Appendix I, Table 1):

Post-exposure absorbance (Post-A_{330}) – Pre-exposure absorbance (Pre-A_{330}) = Absorbance change at 330nm (ΔA_{330}) (3.2)

Table 3.1 Ultraviolet radiation exposure periods used in the calibration process of the PSF against the YES UVB-1 pyranometer

Date	Time	Number of PSF strips	Duration each consecutive PSF strip was exposed for respectively (minutes)
12/02/2001	8:15-10:15 (3 hrs)	3	60; 120; 180
15/02/2001	8:00-16:00 (8 hrs)	8	60; 120; 180; 240; 300; 360; 420; 480
06/03/2001	12:05-12:35 (30 min) 12:35-13:05 (30 min) 13:05-13:35 (30 min)	6 6 6	5; 10; 15; 20; 25; 30
14/03/2001	10:55-11:55 (1 hr) 11:55-12:55 (1 hr) 12:55-13:55 (1 hr)	12 12 12	5; 10; 15; 20; 25; 30; 35; 40; 45; 50; 55; 60

The EUV measured by the YES UVB-1 pyranometer and weighted by the Diffey action spectrum was then extracted for the various days indicated in Table 3.1. Using the exact times that the PSF strips were exposed, the EUV measurements recorded by the YES UVB-1 pyranometer were converted to an EUV dose for each period of exposure. Therefore, the EUV reading, read once off every ten minutes, was multiplied by the duration of the PSF exposure in seconds and used to calculate the cumulative EUV dose for each PSF strip.

The change in absorbance of each PSF strip (ΔA_{330}) was then plotted against the EUV dose (J m^{-2}) calculated using the EUV measurements from the YES UVB-1 pyranometer. Only data points in the range 0 - 0.45 ΔA_{330} were used in producing the final calibration curve indicated in Figure 3.4. The cut-off of 0.45 ΔA_{330} was chosen because of the known ability of PSF to become less responsive to increasing amounts of ultraviolet radiation. Different studies have used different cut-off values where Davis *et al.* (1976) used 0.3 ΔA_{330} and Herlihy *et al.* (1994) and Gies *et al.* (1998) used 0.5 ΔA_{330}. This study used 0.45 ΔA_{330} to accommodate for the high ΔA_{330} measurements although it is acknowledged that the conversion of these values to EUV doses is likely to be less accurate than the lower ΔA_{330} measurements.

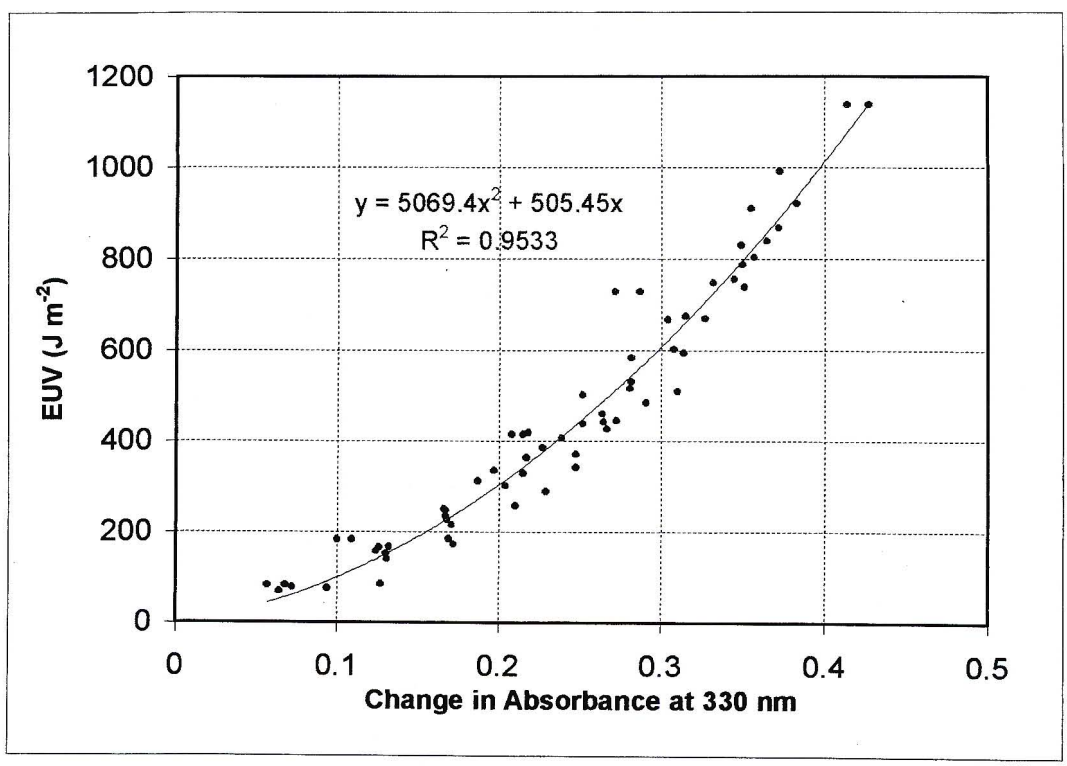


Figure 3.4: Dose-response of PSF showing ΔA_{330} of PSF versus the YES UVB-1 pyranometer EUV dose

In order to relate the measured ΔA_{330} to EUV doses, a quadratic function passing through zero was fitted to the data shown in Figure 3.4. The equation of the calibration curve was $y = 5069.4x^2 + 505.45x$. This equation was then applied in converting all measured ΔA_{330} values to EUV (J m^{-2}). A comparison of this curve and

the calibration curve suggested by Diffey (pers. comm., 2001) is presented in Figure 3.5 and although the order of the polynomial differs, there is acceptable agreement between the two curves.

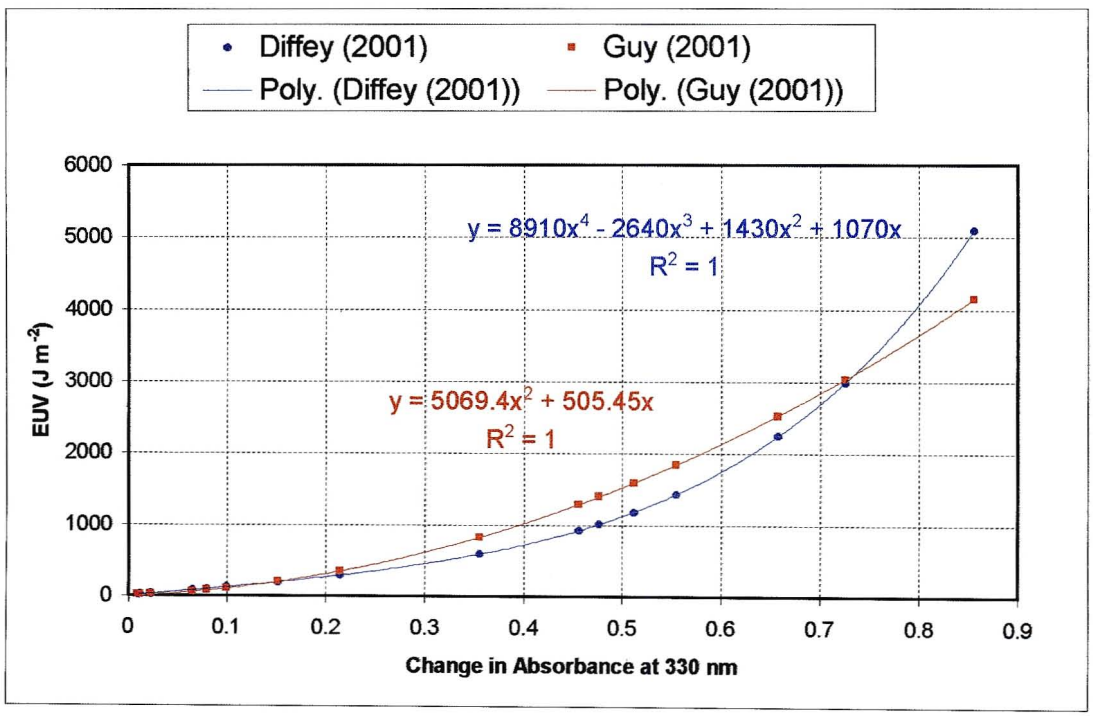


Figure 3.5: Comparison of the calibration curves calculated in this study and by Diffey (pers. comm., 2001)

3.5 Reliability of polysulphone film as an ultraviolet radiation dosimeter

In order to illustrate the validity of using PSF as a means of measuring ultraviolet radiation, PSF strips were exposed for two 2-hour periods on 16 March 2001, 28 March 2001, 29 March 2001 and 2 April 2001, one 1-hour period on 15 March 2001 as well as two 1-hour periods on 9 June 2001, 11 June 2001, 13 June 2001 and 14 June 2001. These days all exhibited clear sky conditions. Pre- and post-exposure absorbance measurements of the PSF strips were done using a Varian DMS 300 UV-Visible spectrophotometer and the ΔA_{330} was applied to the calibration equation to determine the EUV dose (J m^{-2}) of each PSF strip.

The EUV data measured by the YES UVB-1 pyranometer were then extracted for the exact periods of exposure for each of the days identified above and an EUV dose was

calculated for each PSF strip using these data. The results are included in Table 3.2 and Figure 3.6.

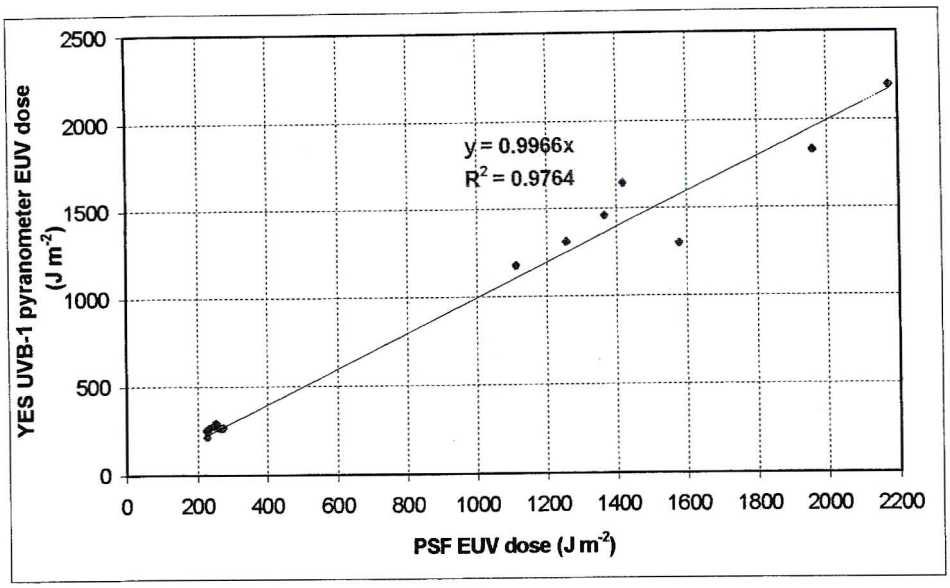


Figure 3.6: Comparison between the PSF EUV measurements and the YES UVB-1 pyranometer EUV measurements for identical periods of exposure

Table 3.2: Comparison between the PSF EUV measurements and the YES UVB-1 pyranometer EUV measurements for identical periods of exposure

Exposure period	Date and duration of exposure period	PSF EUV measurement ($J\ m^{-2}$)	YES UVB-1 pyranometer EUV measurement ($J\ m^{-2}$)
1	9 June 2001 (11:00-12:00)	229.11	214.63
2	11 June 2001 (11:00-12:00)	225.97	251.19
3	14 June 2001 (11:00-12:00)	233.61	260.70
4	9 June 2001 (12:00-13:00)	265.85	265.95
5	13 June 2001 (11:00-12:00)	274.38	265.99
6	13 June 2001 (12:00-13:00)	254.35	272.69
7	14 June 2001 (12:00-13:00)	249.43	281.82
8	11 June 2001 (12:00-13:00)	254.35	291.78
9	2 April 2001 (12:00-14:00)	1111.29	1176.04
10	28 March 2001 (12:00-14:00)	1579.17	1299.60
11	29 March 2001 (12:00-14:00)	1256.54	1308.30
12	2 April 2001 (10:00-12:00)	1365.30	1455.12
13	28 March 2001 (9:00-12:00)	1418.67	1643.72
14	16 March 2001 (12:00-15:00)	1960.37	1826.72
15	16 March 2001 (9:00-12:00)	2177.95	2193.67

There appears to be a fair correlation between the two ultraviolet radiation-measuring devices, particularly at low EUV values while at longer irradiance times PSF becomes less reliable as ΔA_{330} is larger. The differences are likely on account that the YES UVB-1 pyranometer measures EUV between 280 - 320 nm while EUV using the PSF was measured at 330 nm. Nevertheless, PSF is clearly an effective means of measuring EUV.

3.6 Dark reaction

PSF exhibits a dark reaction that refers to the continuation of the depolymerisation process initiated by ultraviolet radiation once the ultraviolet radiation exposure period has ceased (Webb, 1995). This causes the post-exposure absorbance measurement made directly after ultraviolet radiation exposure to be less than that measured 24 hours later (Diffey, pers. comm., 2001). Davis *et al.* (1976) noted that when stored, a previously exposed PSF strip exhibits an increase of 4% after 24 hours, a 5% increase after one week and minimal increase thereafter. This reaction should be taken into account by allowing a constant time period between ultraviolet radiation exposure of the film and measuring its post-exposure absorbance (Parisi *et al.*, 2000a). The constant time period used in this study was a minimum of 24 hours, with the longest period before post-measurement being one week, to ensure that the PSF reading was a true representation of the ultraviolet radiation dose it had received.

In order to test the darkness reaction, three strips of PSF were prepared, their pre-exposure absorbance at 330 nm were measured and they were then exposed to solar ultraviolet radiation for 8 hours between 8:00 and 16:00 on 5 March 2001. The strips were stored in light-impervious envelopes before and after exposure. The post-exposure absorbance measurements were then made at five different times thereafter (Table 3.3). A 6% increase in absorbance of the film was noted 24 hours after ultraviolet radiation exposure. A further increase of 1.9%, 1.5% and 2.2% was calculated after 48 hours, 72 hours and one week respectively. This is in accordance with Diffey (1986) who stated that the increase in absorption of PSF after the abatement of exposure to ultraviolet radiation may be up to 8%. Thereafter, the

increase is sluggish and diminishes over time allowing one to store exposed PSF for up to approximately four months.

Table 3.3: Change in absorbance of PSF over time following ultraviolet radiation exposure

	8 hours post-exposure	24 hours post-exposure	48 hours post-exposure	72 hours post-exposure	168 hours post-exposure (1 week)
ΔA_{330}	0.755	0.801	0.815	0.826	0.843
Percentage increase		6.0%	7.9%	9.4%	11.6%

3.7 Reproducibility

In order to justify the reproducibility of the results of the PSF measurements, two simple procedures were followed. A total of 10 PSF strips were exposed for 30 minutes on 11 November 2001 between 12:30 - 13:00. The pre-exposure absorbance measurements, post-exposure absorbance measurements after 24 hours and the ΔA_{330} nm measurements of the 10 PSF strips are presented in Table 3.4. The range was 41.59 Jm^{-2} with a standard deviation of 16.79 J m^{-2}. The variation in the final EUV dose of each PSF strip may be a result of the film's acquisition of a piece of dust or a slight difference in the positioning of the PSF strip in the Varian DMS 300 UV-Visible spectrophotometer.

Table 3.4: Reproducibility of PSF measurements

PSF strip	Pre-exposure A_{330}	Post-exposure A_{330}	ΔA_{330}	EUV (J m^{-2})
1	0.206	0.504	0.298	600.80
2	0.181	0.479	0.298	600.80
3	0.181	0.471	0.290	572.91
4	0.196	0.482	0.286	559.21
5	0.179	0.469	0.290	572.91
6	0.191	0.478	0.287	562.62
7	0.205	0.491	0.286	559.21
8	0.215	0.512	0.297	597.28
9	0.198	0.486	0.288	566.04
10	0.209	0.500	0.291	576.36

In order to test the reproducibility of the measuring process, one PSF strip was prepared and its pre-exposure absorbance at 330 nm was measured. It was stored in an envelope and exposed for 1 hour between 11:00 - 12:00 on 6 June 2001. The post-exposure absorbance at 330 nm was then measured 24 hours following its exposure.

These post-exposure absorbance measurements were repeated ten times, removing the strip from the spectrophotometer and replacing it each time, in the identical position and orientation, before the following measurement was made. The results are presented in Table 3.5 and indicate that a range of 0.01 ΔA_{330} existed. This was calculated as a range of 4.33 J m^{-2} and a standard deviation of 1.085 J m^{-2}. This difference may be the result of the film's acquisition of a piece of dust or the positioning of the PSF strip. Therefore operator error was smaller than inherent differences in the PSF and is negligible.

Table 3.5: Operator reproducibility of the PSF measurements

Pre-exposure A_{330}	Post-exposure A_{330}	ΔA_{330}	EUV (J m^{-2})
0.246	0.410	0.164	219.24
	0.409	0.163	217.07
	0.409	0.163	217.07
	0.410	0.164	219.24
	0.410	0.164	219.24
	0.410	0.164	219.24
	0.409	0.163	217.07
	0.410	0.164	219.24
	0.410	0.164	219.24

3.8 Personal ultraviolet radiation dosimetry

Personal ultraviolet radiation dosimeters have been described as a reliable means of quantifying an individual's EUV dose. A polysulphone film badge (PSFB) has the advantage of being relatively small, sturdy and discrete. For the purpose of this study,

PSFBs were used to quantify the daily EUV dose of children and adolescents in Durban.

3.8.1 Recruitment of subjects

Three groups of subjects were identified based upon similar studies conducted by Diffey *et al.* (1996) and Moise *et al.* (1999a). The three age groups were 4 - 6, 7 - 9 and 13 - 14 years of age, allowing for a suitable variation in children's behaviour while attending the different stages of the South African school system. Volunteer subjects for each of the three age groups were recruited from four schools: Panda Pre-Primary School, Marlborough Park Junior Primary School, Durban Girls' High School and Glenwood High School (Plate 3.3). Figure 3.7 illustrates the locations of the four schools within an 8-km radius of the University of Natal (Durban). The selection of schools was made according to their proximity to the University of Natal (Durban) campus and their willingness to participate in the study.

The financial costs incurred in importing the PSFBs restricted the total number of badges and consequently the total number of subjects. A total of 210 badges were obtained and allowed for 10 subjects per age group to wear one badge per day for 7 days (1 week). Each age group was further subdivided into five males and five females to ensure an equal gender distribution. Each gender was further allocated a minimum of three light-skinned individuals and two medium or dark-skinned individuals. The skin type and skin colour classification system used in this study was presented in Table 2.3 and Figure 2.9. Light and medium-skinned individuals were focused upon due to the higher risk factors associated with these skin types in terms of the adverse impacts of ultraviolet radiation exposure.

The recruitment of subjects was done on a volunteer basis. A preliminary meeting was held with the relevant educator at each school and the requirements of the study were discussed. A second interactive meeting was held with the educator's class to inform them of the study, to discuss any questions and to ask for interested class members to volunteer to wear the badges. From the list of volunteers, those fulfilling the necessary criteria and deemed eager, enthusiastic, genuinely interested and capable of keeping simple records as well as complying with the badge-wearing requirements

were selected to participate. A group discussion was then initiated to involve the rest of the class in the study and to support their classmates in their respective duties.

(a)

(b)

(c)

(d)

Plate 3.3: The four groups of children and adolescents involved in the study (a) 4 - 6 years; (b) 7 - 9 years; (c) 13 - 14 years; and (d) 13 - 14 years

Parents of the volunteer subjects were notified of their child's involvement in the study and their consent was obtained. Letters were sent to the principal of each school and the parents/guardians of the volunteers. A consent form was signed by each volunteer's parent/guardian. Copies of these documents are included in Appendix II.

Ethics approval for this study was granted by the Ethics Committee located at the Nelson Mandela Medical School of the University of Natal (Durban).

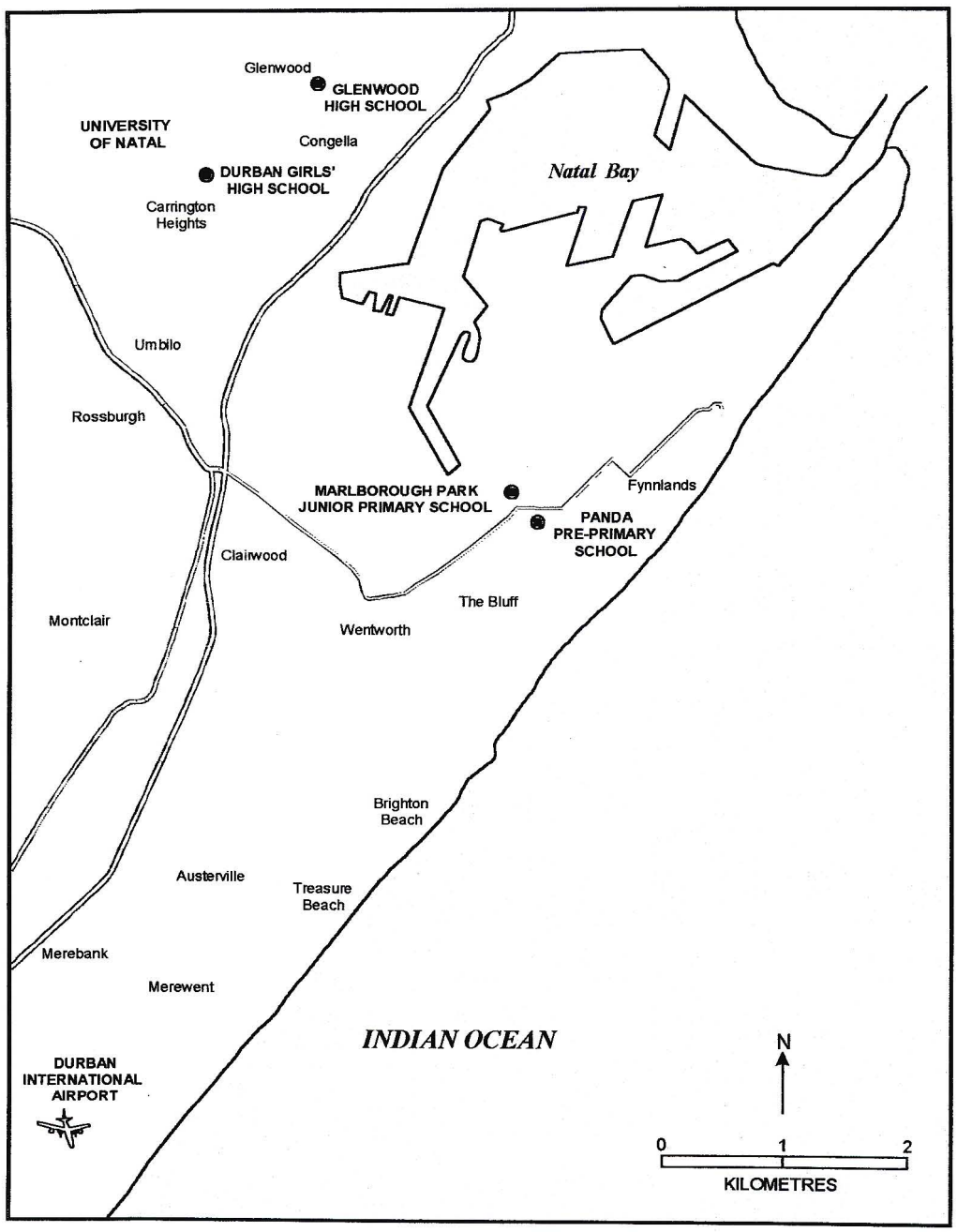


Figure 3.7: Diagrammatic sketch of Durban showing the four schools involved in the study

3.8.2 Polysulphone film badges

The PSFBs consisted of a strip of PSF mounted in a type 110 cardboard photographic mount with a medium-sized safety pin attached to one side of the cardboard mount

(Plate 3.4). The cardboard mount provided the badge with a durable and sturdy frame. The badge dimensions were 2.5 cm x 3 cm with a central aperture of 1.2 cm x 1.6 cm (1.92 cm^2) of exposed PSF. Each badge was allocated a number from 1 to 210 and stored in a correspondingly numbered, brown envelope. The colour and quality of the envelope ensured that it was impervious to ultraviolet radiation.

Plate 3.4: A polysulphone film badge

The pre- and post-exposure absorbance measurements at 330 nm were measured on a Varian DMS 300 UV-Visible spectrophotometer. Each PSFB was placed in the same position and orientation within the spectrophotometer. Once the pre-exposure measurements were complete the encased PSFBs were divided into groups of seven, numbered 1 - 7 and stored in a large sealed envelope as part of a resource kit. Each subject received one resource kit containing 7 PSFBs. One PSFB was worn per day for one week from 26 February 2001 to 4 March 2001. The PSFBs were attached to the left lapel site of the body, beneath the clavicle and between the shoulder and the center of the chest. This was in accordance with studies conducted by Diffey *et al.* (1982) and Holman *et al.* (1983). The lapel site is thought to provide a good approximation of the ultraviolet radiation dose received by the hands and the face (Diffey *et al.*, 1982). The PSFB was pinned to the clothing of the subject, parallel to the natural contour of the body, assuming that it would receive an EUV dose approximating that received by the skin directly underneath, had the skin been exposed. This also provided an indication of the EUV dose received by the hands and face.

Each subject wore one unexposed PSFB per day from the time that they awoke until the time that they retired. It was assumed that indoor lighting, e.g. fluorescent lights, would not significantly influence the EUV dose of the PSF. The PSFB was only

removed during bathing and swimming since the mount was not waterproof and was placed in a dry, non-shaded location in close proximity to the subject. All subjects were strongly advised not to immerse the PSFB in water or any other liquid to prevent disintegration of the cardboard mount. PSFBs were to be removed and stored in their envelopes in the case of rain. The PSFBs were not to be covered by jerseys, blazers or any other pieces of clothing. If the subject changed into a new outfit, for example, for a sport or extramural activity, they were requested to re-attach the PSFB to the newly adorned item of clothing.

The PSFBs were collected from each school on 5 March 2001. The post-exposure absorbance measurements were conducted on 6 March 2001. This ensured that all of the PSFBs remained in a sealed envelope for a minimum of 24 hours following their EUV exposure. The change in absorbance at 330 nm was calculated for each PSFB and its EUV dose was determined through the application of the dose-response curve presented in Figure 3.4. Pre-exposure absorbance measurements, post-exposure absorbance measurements and EUV measurements of all badges are included in Appendix III (Table 2). Eighteen PSFBs were either misplaced or damaged by crayons, blood, glue, scissors and ink during the study, resulting in a good return of 192 observations or person-days. The subjects' PSFB doses were used to discuss the relationship between personal ultraviolet radiation and ambient ultraviolet radiation in Section 4.5, as well as the relationship between personal ultraviolet radiation dose as a function of age, gender, skin type, behaviour and activities in Section 4.7.

3.8.3 Personal ultraviolet radiation exposure journal

Each subject received a personal ultraviolet radiation exposure journal. A condensed version of journal is included Appendix IV. The journal consisted of a general introduction and background to the study; an indication of the subject's educator/parent/guardian's responsibilities in the study; guidelines on how to complete the journal and important notes about the PSFBs handling sensitivities. The journal was to be completed on a daily basis for the 7 consecutive days of the study. Subjects between the ages of 4 - 9 years were required to work with their educator and their parents in order to complete the journal. Table 3.6 illustrates the nature of the information recorded in the journal.

Table 3.6: Example of typical journal entry

Time of activity	Type of activity	Inside/Outside. If outside, in the sun or the shade.	Type of clothing worn	Using sunscreen
6:45 – 7:15	Driving in car to school	Inside	School blazer	No
7:15 – 10:00	Sitting in classroom	Inside	School shirt	No
10:00 – 10:45	Sitting in field during break	Outside, shade	School shirt	No
10:45 – 11:30	Swimming in school pool	Outside, sun	Swimming costume	Yes
11:30 – 13:00	Sitting in classroom	Inside	School shirt	No
13:00 – 13:30	Sitting on field during break	Outside, sun	School shirt	No
13:30 – 14:30	Sitting in classroom	Inside	School shirt	No
14:30 – 15:00	Sitting on bus	Inside	School blazer	No
15:00 – 16:30	Playing tennis	Outside, sun	T-shirt	Yes
16:30 – 17:00	Driving in car	Inside	T-shirt	No
17:00 – 19:00	Working on computer	Inside	T-shirt	No

It was assumed that the journal entries were a true representation of the subject's ultraviolet radiation exposure patterns. Where subjects indicated that they were outside and in the sun, it was assumed that they were fully exposed to ultraviolet radiation. If the subject indicated that they were in a car or in a classroom it was interpreted as being indoors. This assumption was made based on the complexity of factors determining the EUV dose of an individual whilst in a car, including window tinting, seating location and sitting besides an open or closed window (Parisi and Wong, 1999; Parisi and Kimlin, 2000).

If the subject indicated that they were outside during break but did not indicate whether they were in the sun or the shade, it was interpreted as being in the shade. These journal entries were then used to determine the exposure periods and exposure duration of each subject on a daily basis.

3.9 Ambient ultraviolet radiation and human ultraviolet radiation doses

An EUV dose received by an individual depends on three factors including ambient ultraviolet radiation, the fraction of the ambient ultraviolet radiation received by a particular anatomic site and the exposure patterns of an individual while outdoors (Diffey, 1992). In order to estimate the potential EUV dose (J m^{-2}) received by each subject, the ambient EUV measurements, made by the YES UVB-1 pyranometer, were used to calculate each subject's total daily EUV dose by adding together the calculated ambient EUV doses for each of the subject's exposure periods as recorded in their journals on a particular day. In this manner a potential EUV dose was calculated based upon time outdoors for each subject. This EUV dose was then directly compared to the PSFB dose for each subject on the corresponding day and the PSFB doses were also calculated as a percentage of each measured total daily ambient EUV value for that particular day.

A slightly more sophisticated method of calculating an individual's EUV dose is that of Parisi (pers. comm., 2001) which takes into account the anatomic site, a sun protection factor and an activity index. The equation is given as follows:

$$EUV \cdot dose = \sum \left(\frac{(AE \times t) \times AI \times ER}{PF} \right) \qquad (3.3)$$

where AE is the ambient EUV (J m^{-2}), t is the time spent outdoors (seconds), AI is an activity index ranging between 0 and 1 where 0 is for activities conducted inside, 0.5 for those conducted outside in the shade and 1 for outside in the sun. The exposure ratio for a particular anatomic site is ER and PF is the sun protection factor governed by the use of sunscreen or a hat.

The ambient EUV was calculated using the YES UVB-1 pyranometer data and the protection factor was assumed to be 1 to avoid the complexities of determining the protection provided by a hat or sunscreen and thus provide for the worst-case scenario. The activity index was used to weight the EUV dose by the nature of exposure, either in the sun or in the shade. The exposure ratio indicates the percentage of ambient EUV incident upon a particular anatomic site. Since the PSFBs worn by

the subjects were attached to the lapel the exposure ratio utilised was 0.44. This exposure ratio was derived from two studies (Diffey *et al.*, 1977 and Holman *et al.*, 1983) using the average value for the shoulder and chest EUV doses as a percentage of the vertex to represent that of the lapel site for living subjects. Results are discussed in Section 4.5.

3.10 Meteorological data

Surface meteorological data were obtained courtesy of the South African Weather Service (SAWS) for the period 26 February 2001 - 4 March 2001 when the subjects wore the PSFBs as well as for other days on which fieldwork took place. The data included maximum and minimum temperatures, average daily wind speed and direction, average daily humidity, hours of sunshine per day, cloud cover and daily rainfall. The weather data were measured at the Durban International airport situated approximately 10 km southwest of the University of Natal (Durban). Cloud cover was quantified as a portion of eighths where 1 eighth = 1 octa and 1 eighth of the sky dome was covered by cloud, as observed by a trained meteorologist.

Meteosat satellite images of the eastern portion of southern Africa were acquired from the SAWS. The visible images were taken at 12:00 on each day. They were utilised to illustrate clear sky conditions for the investigation of the anatomical distribution of ultraviolet radiation discussed below.

3.11 Anatomical distribution of ultraviolet radiation

The human body consists of many planes and angles and thus different anatomic sites receive different ultraviolet radiation doses as a result of their orientation as well as the angle of the sun. A mannequin was employed to calculate the EUV dose incident upon various anatomic sites. PSF strips were attached to 26 different parts of the body. Two PSF strips were used as controls and placed on a horizontal surface approximately one metre away from the mannequin.

The mannequin was placed in standing position on a grassed, non-shaded location on five different days: 6, 9, 11, 13 and 14 June 2001. The body of the mannequin was

cream in colour and was assumed to cause negligible reflectance. The mannequin was placed in a vertical position for all exposure periods. Days were selected according to clear sky conditions with no cloud cover in order to eliminate the effects of clouds. Care was taken to ensure that these days did not exhibit any signs of photochemical smog or haze. The mannequin was exposed to EUV from approximately 11:00 - 12:00 and 12:30 - 13:30 on each of the five days. The PSF strips were changed after one hour of ultraviolet radiation exposure and replaced with unexposed PSF strips in order to ensure that the ΔA_{330} units did not exceed 0.45.

Pre- and post-exposure absorbance measurements at 330 nm were conducted using the Varian DMS 300 UV-Visible spectrophotometer and ΔA_{330} was calculated for each anatomic site. The EUV doses were calculated using the calibration equation presented in Section 3.4 (Figure 3.4). The averages of these values for the five days were calculated and used as the EUV doses for each of the anatomic sites (Appendix V; Table 4).

3.11.1 Exposure distribution

The identification of anatomic sites for which the EUV doses were quantified was based upon the distribution of NMSC and MMSC (Plate 2.5). PSF strips were placed on 26 different anatomic sites illustrated in Figure 3.8 and listed in Table 3.7.

3.11.2 Orientation and positioning

The mannequin was approximately 1.8 m in height and stood with the right leg forward and left leg back, with a 0.5 m distance between the two feet. The right arm was held at a 90□ angle to the stomach (Plate 3.5). The orientation of the mannequin was standardised such that it faced true north for the first 15 minutes of each ultraviolet radiation exposure period.

Table 3.7: The 26 anatomic sites used to measure the EUV doses for clear sky conditions

Number	Anatomic site	Number	Anatomic site
1	Vertex of the head	14	Front of right hand
2	Forehead	15	Back of right upper arm
3	Bridge of nose	16	Back of right elbow
4	Chin	17	Right scapular
5	Left cheek	18	Nape of neck
6	Right temple	19	Centre of upper back
7	Top of left ear	20	Centre of lower back
8	Side of left ear	21	Right kneecap
9	Left lapel	22	Back of left knee
10	Right shoulder	23	Front of right mid-calf
11	Centre of chest	24	Back of left mid-calf
12	Front of right upper arm	25	Front of right foot
13	Front of right mid-forearm	26	Back of left ankle

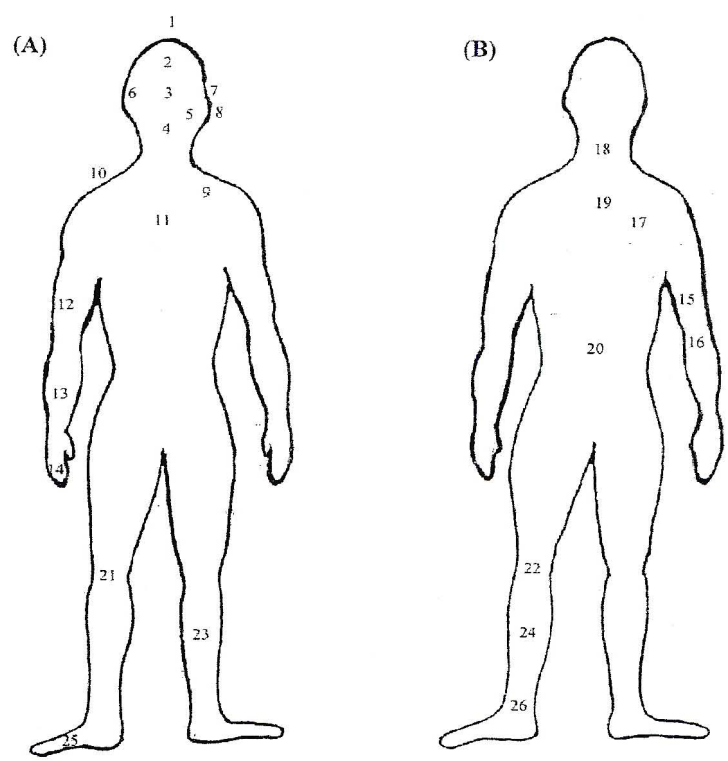


Figure 3.8: Diagrammatic sketch showing the 26 anatomic sites on the (A) front and (B) back of the human body

A magnetic compass was used to determine magnetic north. The mean magnetic declination was calculated as 23°03′ west based on a mean annual change of 9′ westwards and magnetic declination of 22°00′ west of true north (January 1994). The mannequin was rotated 45° to the right every 15 minutes completing a 360° revolution in 1 hour and therefore exposing each of the four sides of the body for 15 minutes towards true north.

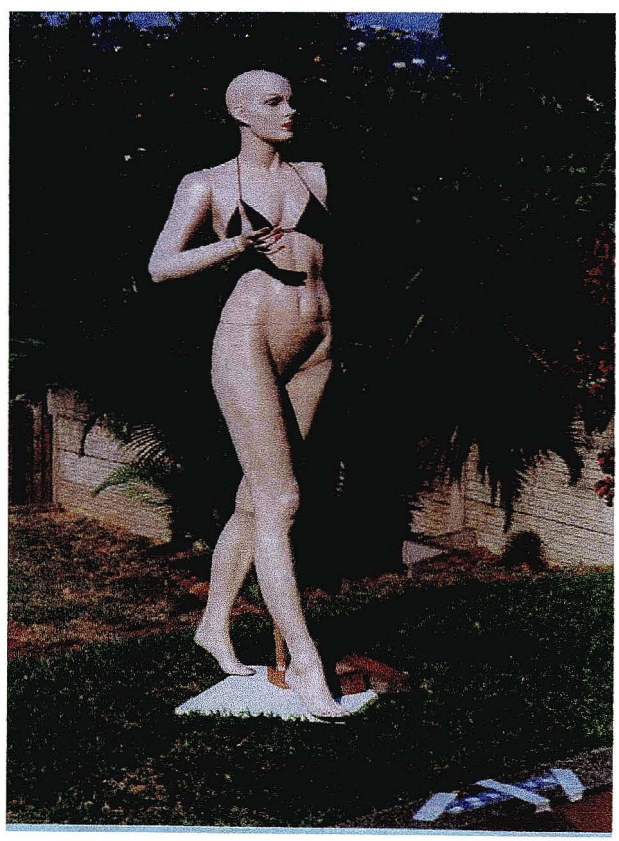


Plate 3.5: The mannequin used in this study

3.11.3 Data analysis and utilisation

The mean EUV doses of each anatomic site were calculated as a percentage of the vertex dose and compared with values computed by Diffey *et al.* (1977; 1979) and Kimlin *et al.* (1997). They were also expressed as percentages of the total daily ambient EUV measured by the YES UVB-1 pyranometer as well as for the actual period that the PSF strips were exposed. The anatomic EUV doses were categorised in order to determine susceptible anatomic zones and this was related to the anatomic

distribution of NMSC and MMSC in light-skinned individuals. Results are discussed in Sections 5.2.

3.11.4 Cloud cover and the anatomical distribution of ultraviolet radiation

Cloud has been identified as an important factor influencing the daily variation in ultraviolet radiation received at the earth's surface. A mannequin was used to investigate the influence of heavily overcast skies on the anatomical distribution of ultraviolet radiation. Following the procedure adopted for the clear sky conditions, the mannequin was exposed to ultraviolet radiation on 2 different days, 15 August and 31 August 2001, selected according to overcast sky conditions. This was assessed by personal observation such that the solar disk was completely obscured by cloud cover and there was no likelihood of clearing.

Due to the reduced levels of surface EUV in Durban during winter it was necessary to expose the mannequin for 2 hours around local noon. The periods of exposure to ultraviolet radiation were approximately 10:00 - 12:00 and 12:30 - 14:30 and the PSF strips were changed after two hours. The mannequin was orientated towards true north and rotated 45° to the right every 15 minutes.

The EUV doses of the 26 anatomic sites were investigated to deduce the anatomical distribution of ultraviolet radiation during overcast conditions. Pre- and post-exposure absorbance measurements at 330 nm for each of the strips were done using the Varian DMS 300 UV-Visible spectrophotometer and ΔA_{330} was calculated for each anatomic site. The EUV doses for each anatomic site were then calculated using the calibration equation presented in Figure 3.4 and these data are included in Appendix V (Table 4). The averages of these values for the two days were calculated and used as the EUV doses for each of the anatomic sites under overcast conditions.

These EUV doses were calculated as a percentage of the ambient EUV received on a horizontal surface as recorded by the PSF control strip and as a percentage of the vertex dose in order to compare the anatomical distribution of ultraviolet radiation for clear and cloudy conditions. Observations were also made regarding the influence of

overcast skies in reducing the EUV dose of all anatomic sites. Results are discussed in section 5.3.

The following chapter considers the results of the daily PSFB doses of the children and adolescents in Durban in relation to ambient EUV and various factors including age, gender, skin type and behaviour.

Chapter Four

ULTRAVIOLET RADIATION DOSIMETRY OF CHILDREN AND ADOLESCENTS IN DURBAN

4.1 Introduction

Epidemiological studies have indicated that for MMSC and possibly even NMSC, exposure to ultraviolet radiation during childhood and adolescence is particularly important in determining the subsequent risk of developing skin cancer during adulthood. Previous studies have examined different solar protection behaviour of young people, recorded episodes of erythema incidents and measured the ultraviolet radiation exposure of young people taking part in sports and outdoor activities. However, there are no data available on the daily erythemal ultraviolet radiation (EUV) dose and exposure of children and adolescents over an extended period of time for the South African environment.

This chapter presents the results of the daily PSFB doses and ultraviolet radiation exposure patterns of 30 young residents of Durban, South Africa during a one-week period in summer. These results were analysed in an attempt to understand the effects of age, gender, skin type and behaviour patterns on an individual's ultraviolet radiation dose. Environmental and behaviour factors are both important in understanding the ultraviolet radiation dose and exposure patterns of people. A comparison is made with ambient EUV levels and various methods are used in order to determine the relationship between ambient ultraviolet radiation conditions and the ultraviolet radiation dose received by human beings.

4.2 Ambient environmental conditions

A background on the ambient environmental conditions experienced during the study period, including surface ultraviolet radiation levels and meteorological conditions, will be provided before analysing the daily PSFB doses of the children and adolescents.

4.2.1 Surface ultraviolet radiation conditions

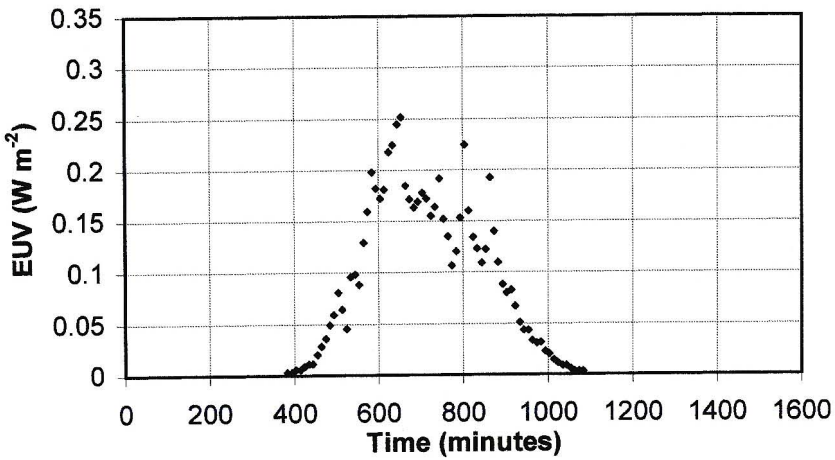
Ambient EUV was monitored throughout the study period at Durban by using a YES UVB-1 pyranometer as described in Section 3.3. The variation of EUV (W m^{-2}) with time of day for each of the 7 days of the study is shown in Figure 4.1. Total daily ambient EUV values were also converted into MED units where 1 MED = 200 J m^{-2} (Table 4.1). The ambient EUV levels are typical of those received during the late summer months in Durban, with solar noon values ranging between approximately 0.25 - 0.35 W m^{-2}. The diurnal curves are symmetrical and bell-shaped about solar noon, with zero values recorded between 0:00 - 6:00 and 18:00 - 24:00 when solar exposure was nil.

Table 4.1: Total daily integrated erythemal irradiances and MED values for the study period

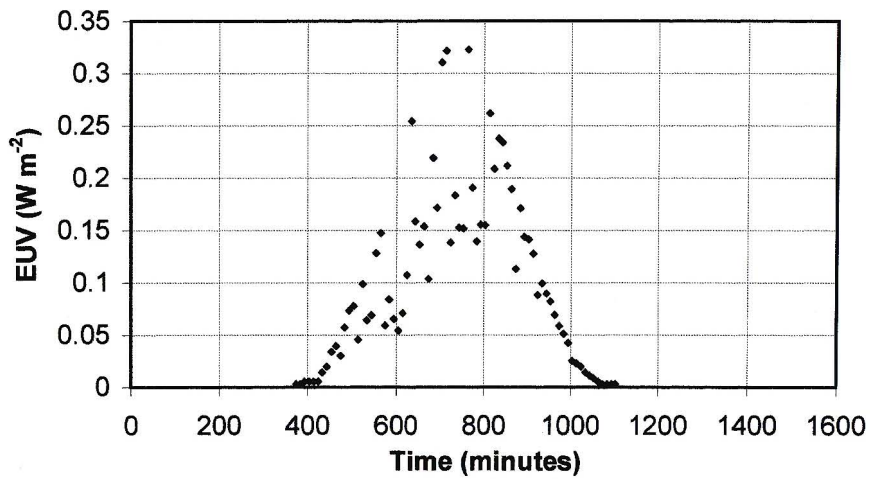
Day of study	Date	Day of the year	Daily integrated erythemal irradiances (J m^{-2})	MED values
1	26 February 2001	57	6107.40	30.5
2	27 February 2001	58	4114.93	20.5
3	28 February 2001	59	4522.20	22.6
4	1 March 2001	60	6120.93	30.6
5	2 March 2001	61	5616.61	28.1
6	3 March 2001	62	5919.79	29.5
7	4 March 2001	63	5641.40	28.2
Mean			5434.75	27.1

Temporal fluctuations in ambient EUV on each day during the study period are also evident (Figure 4.1). These are primarily the result of cloud cover as clouds produce a deviation from the typical bell-shaped distribution. It is expected that on clear sky days total MED values would exceed those for cloudy days, however, this is not always the case. The relationship between cloud cover and ambient EUV exhibited during the study period shows that scattered cloud may enhance ambient EUV by approximately 15% of that received on clear sky days. The discrepancy in the cloud cover readings and the ambient EUV readings may be on account of the distance between the South African Weather Service (SAWS) observation site at the Durban International Airport and the location of the YES UVB-1 pyranometer at the

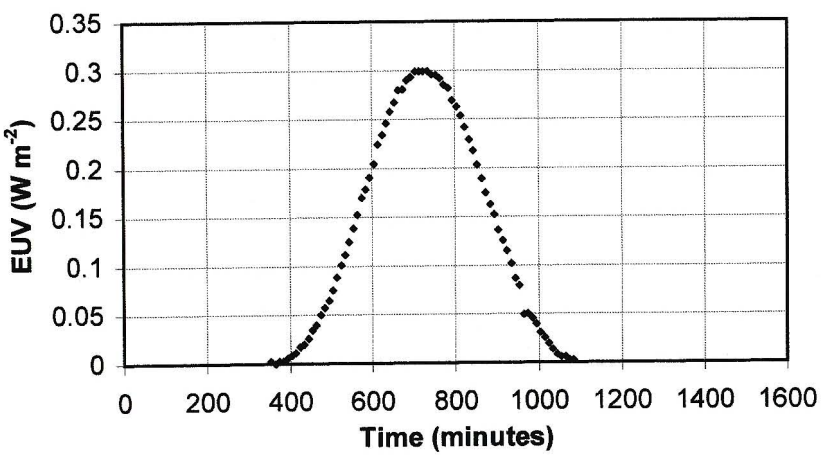
(a) Day 1: 26 February 2001 (Day 57)



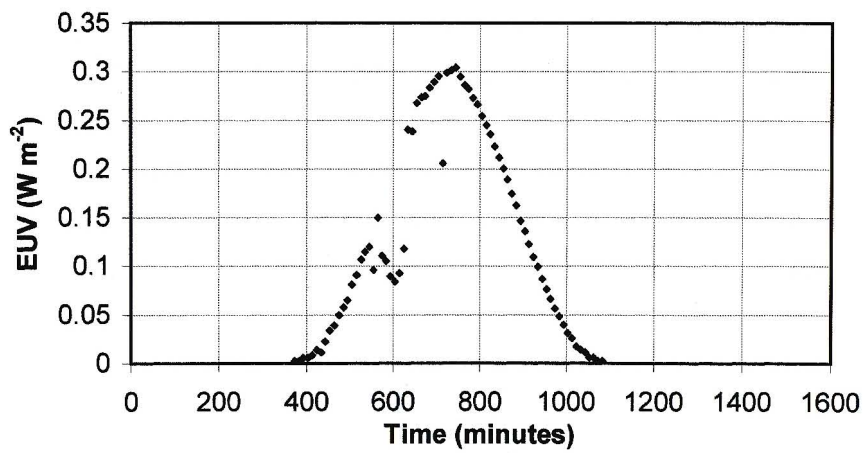
(b) Day 2: 27 February 2001 (Day 58)



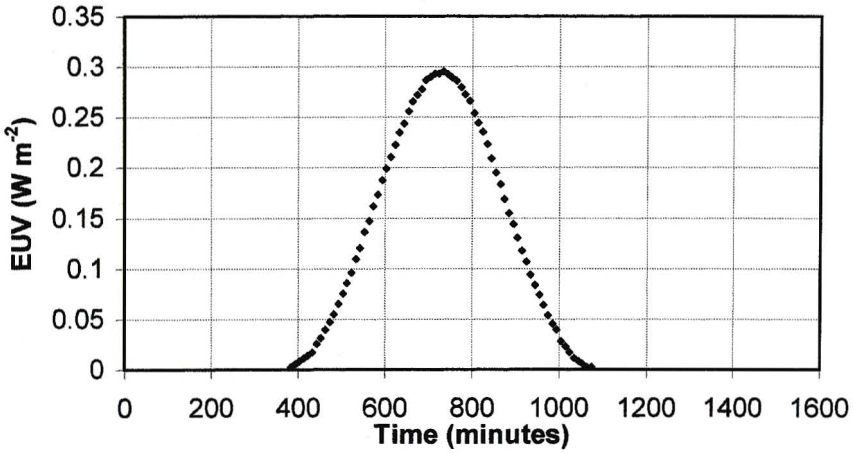
(c) Day 3: 28 February 2001 (Day 59)



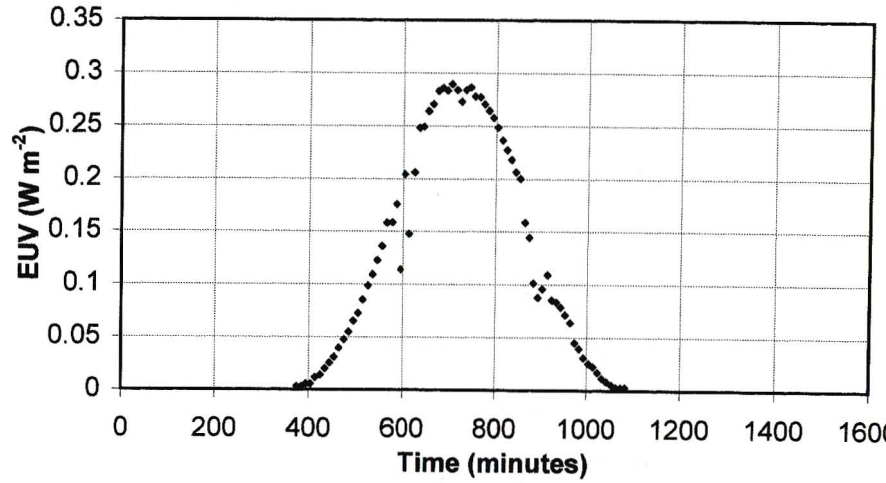
(d) Day 4: 1 March 2001 (Day 60)



(e) Day 5: 2 March 2001 (Day 61)



(f) Day 6: 3 March 2001 (Day 62)



(g) Day 7: 4 March 2001 (Day 63)

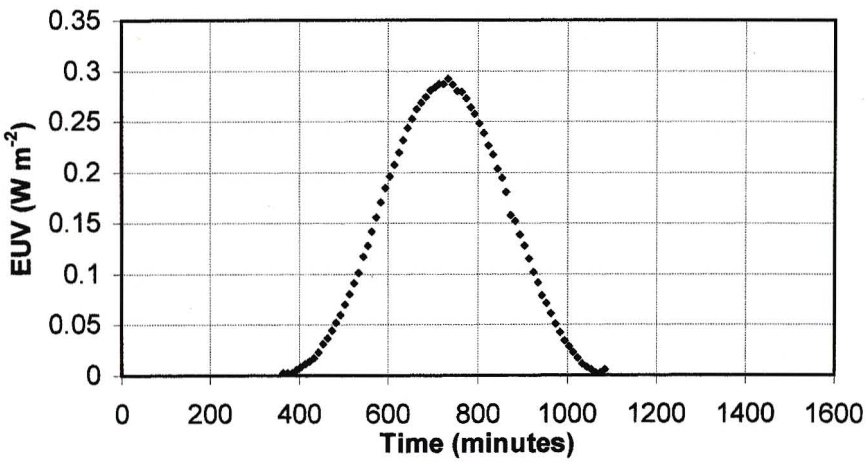


Figure 4.1: Ambient EUV (W m^{-2}) as recorded by the YES UVB-1 pyranometer in Durban for the 7 days of the study period

University of Natal (Durban) in terms of the spatial variability of cloud cover (Table 4.2). Days 1 and 2 show much variability in ambient EUV as a result of scattered cloud, however, the total daily MED value for day 1 is higher than day 5 when partly cloudy skies prevailed. Day 2 has the lowest total daily MED value of 20.5 as a result of cloud cover values ranging between 5 - 6 octas during the day.

Table 4.2: Cloud cover readings measured in octas, for total cloud at all heights and for all types of clouds, at 8:00, 14:00 and 20:00 for the study period (Courtesy of: SAWS, 2001)

Day of study	Date	8:00	14:00	20:00
1	26 February 2001	4	5	3
2	27 February 2001	6	6	5
3	28 February 2001	5	4	1
4	1 March 2001	1	3	3
5	2 March 2001	3	1	0
6	3 March 2001	0	0	4
7	4 March 2001	2	2	2

The typical annual cycle in EUV in MED units for Durban is presented in Figure 4.2, where it is evident that values range between approximately 10 - 40 MED units. The distribution is markedly symmetrical about the winter solstice (21 June, Day 172) as a result of the seasonal variation in earth-sun separation, total column ozone and solar zenith angle. The 7 days of the study period, days 57 - 63, clearly fall in the late summer months during which period a full day's exposure to ultraviolet radiation is likely to result in skin damage, as total daily MED values are relatively high, i.e. greater than 25 MED units (Table 4.1). The risk of skin damage is heightened due to the perception that since the solar disk may be temporarily obscured by cloud, people tend to spend longer outdoors, especially during periods of high surface ultraviolet radiation levels, i.e. between 10:00 and 15:00, and consequently still receive high EUV doses.

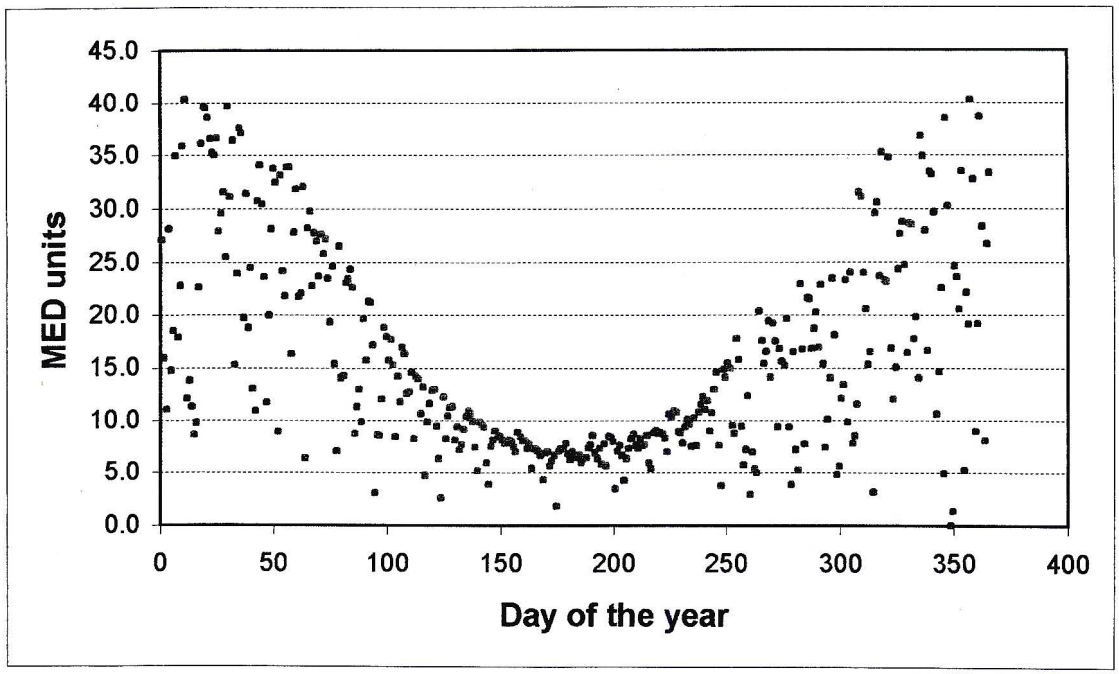


Figure 4.2: Annual variation in EUV (MED units) for the year 2000 as recorded by the YES UVB-1 pyranometer

4.2.2 Meteorological conditions

Table 4.3 provides additional regional meteorological data measured at the Durban International Airport for the study period. Temperatures ranged between a mean minimum of 20.0°C and mean maximum of 28.5°C. Sunshine hours were less on days 1 and 2 when scattered cloud cover was experienced (Table 4.2). Maximum relative humidity values were high, ranging between 81 - 91%, creating hot and humid conditions.

Figure 4.3 compares the total daily MED values and the sunshine hours for the 7 days of the study period. Day 2 illustrates the relationship between reduced ambient EUV as a result of reduced sunshine hours most likely on account of cloud cover ranging between 5 - 6 octas. Day 1 has a high MED value of 30.53 units and high cloud cover (3 -5 octas) while the sunshine hours are relatively lower than days 3 - 7. This highlights the complexity involved in assessing the relationship between cloud cover and ultraviolet radiation at the earth's surface. These climatic data will be used later in the discussion of the daily PSFB doses of the children and adolescents.

Table 4.3: Meteorological conditions for the study period as recorded at the Durban International Airport (Courtesy of: SAWS)

Day of study	Date	Min Temperature (°C)	Max Temperature (°C)	Wind direction	Mean Wind speed ($m\ s^{-1}$)	Humidity (Min) (%)	Humidity (Max) (%)	Sunshine Hrs	Rain (mm)
1	26 Feb 2001	20.4	27.7	NW	5.8	62	90	6.8	-
2	27 Feb 2001	22.1	27.3	NW	4.2	55	81	3.6	0.1
3	28 Feb 2001	21.4	27.6	NW	2.9	54	87	10.3	-
4	1 Mar 2001	18.3	28.9	NW	3.3	52	86	10.3	-
5	2 Mar 2001	19.3	28.1	SE	3.0	59	89	11.7	-
6	3 Mar 2001	17.9	31.2	SW	4.0	47	91	11.2	-
7	4 Mar 2001	21.0	29.1	SE	3.4	47	81	10.9	-

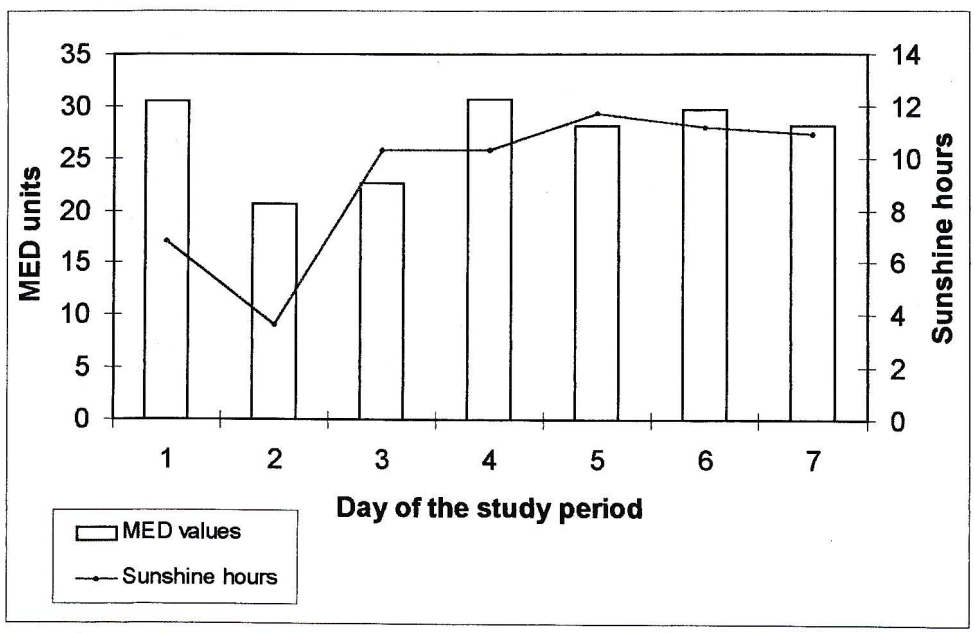


Figure 4.3: Comparison between the total daily MED values and the recorded sunshine hours for the 7 days of the study period

4.3 Characteristics of subjects

The ultraviolet radiation doses of 20 children and 10 adolescents were quantified using PSFBs attached to the left lapel site of their clothing. Pre- and post-exposure absorbance measurements were done and the ΔA_{330} was calculated for each PSFB (Appendix III, Table 2). Using the calibration equation in Figure 3.4, the EUV dose ($J\ m^{-2}$) of each PSFB was determined and this was then converted to MED units using

the conversion 1 MED = 200 J m^{-2}. Whilst 96% of the PSFBs were returned, included amongst these were some that were not worn (mostly on weekend days) and some that were damaged and unreadable. Consequently a total of 202 PSFBs were returned and 192 (91%) were used in the analysis.

In order to relate the PSFB doses to various factors the characteristics of all the subjects are presented in Table 4.4. Each subject was assigned a number that will be used in subsequent tables as well as to identify individual PSFB doses pertaining to each subject in Appendix III. Skin colour was assessed by using a skin colour chart (Figure 2.9). Weinstock *et al.* (1989) state that skin sensitivity is determined on the basis of skin colour, hair colour, eye colour and other genetic factors. Individuals with sensitive skin responses to ultraviolet radiation exposure tend to have light eye and hair colour. Fourteen of the subjects had skin type III, six had skin type II and one had skin type I. Thus, almost half of all the subjects had relatively sensitive skin. An additional means of assessing skin sensitivity is the number of melanocytic nevi or precursor lesions present on the inner arm of each subject (Moise *et al.*, 1999b). However, this indicator was not used in this study.

4.4 PSFB doses of subjects

Analysis of the daily PSFB doses of the children and adolescents in this study showed that the mean PSFB dose was 1.03 MED units per day, with a median of 0.57 MED units and a 95% range of 0.22 - 7.22 MED units (Table 4.5). The 95% range was utilised for comparative purposes with similar studies and was calculated as the mean ± 2 standard deviations. The highest mean PSFB dose of 1.39 MED units was for Sunday (Day 7), while the lowest of 0.53 MED units was recorded on Friday (Day 5).

The median is frequently used in personal ultraviolet radiation exposure studies as a more representative method of summarising the data in order to avoid large variations in individual's radiation exposures (Diffey *et al.*, 1996; Moise *et al.*, 1999b; O'Riordan *et al.*, 2000) and is therefore adopted in this study.

Table 4.4: Characteristics of each subject who participated in this study

Subject no.	Age group	Age	Gender	Hair colour	Eye colour	Skin colour	Skin type
1	4–6 years	5	Female	Blonde	Green	3	III
2		5	Female	Brown	Green	4	III
3		5	Female	Black	Brown	3	III
4		6	Female	Blonde	Brown	2	II
5		6	Female	Black	Brown	5	V
6		6	Male	Black	Brown	6	V
7		4	Male	Black	Brown	6	V
8		6	Male	Black	Brown	6	V
9		6	Male	Brown	Blue	3	II
10		6	Male	Blonde	Blue	2	II
11	7–9 years	7	Female	Brown	Brown	3	III
12		8	Female	Blonde	Brown	2	II
13		8	Female	Brown	Brown	3	III
14		8	Female	Red	Brown	4	III
15		9	Female	Brown	Brown	4	III
16		8	Male	Red	Blue	2	II
17		8	Male	Brown	Brown	3	III
18		8	Male	Black	Brown	6	V
19		8	Male	Brown	Blue	4	III
20		8	Male	Brown	Blue	4	III
21	13-14 years	13	Female	Black	Brown	6	V
22		13	Female	Brown	Green	4	III
23		13	Female	Blonde	Blue	3	III
24		13	Female	Brown	Brown	4	III
25		14	Female	Black	Brown	6	V
26		13	Male	Blonde	Blue	2	II
27		14	Male	Brown	Brown	4	III
28		14	Male	Black	Brown	6	V
29		14	Male	Blonde	Blue	1	I
30		14	Male	Black	Brown	5	V

The median PSFB doses for all subjects over the 7 days of the study period ranged between 0.46 - 0.86 MED units. The most striking finding is that these values lie below the critical value of 1 MED unit and are therefore not sufficient to induce minimal reddening of the skin for the average skin type. However, amongst the 95%

range of subjects' PSFB doses there was evidence of higher PSFB doses exceeding 3 MED units on each day of the study period. This was indicative of the variability in behaviour patterns of children and adolescents and may justify the need for a more specific approach to analysing personal ultraviolet radiation dosimetry rather than formulating broad generalizations. It should be noted that the PSFBs were worn on the outside of the subject's clothing and thus received the highest potential ultraviolet radiation that could conceivably be received since clothing does offer a certain degree of protection (Moise *et al.*, 1999a).

Table 4.5: The mean, median and 95% range of the daily PSFB doses in MED units (1 MED = 200 J m^{-2}) for all subjects

	Day of the week							
	1	2	3	4	5	6	7	**Mean**
Mean	1.06	0.76	1.11	0.67	0.53	1.03	1.39	1.03
Median	0.86	0.63	0.56	0.48	0.50	0.62	0.46	0.57
95% range	0.09-3.67	0.11-3.12	0.28-6.04	0.10-3.90	0.12-4.87	0.15-5.85	0.18-7.22	0.22-7.22

These results suggest that members of a young population may be distributed across a significantly broad risk continuum because of wide variability in individual behaviour, resulting in a range of ultraviolet radiation exposure patterns. The South African lifestyle is diverse, evident from a relatively small sample size, and children of similar ages do not act as a homogenous group with respect to outdoor activities. The relationship between the subjects' PSFB doses and various activities as indicated in their journals will be covered in Sections 4.8 and 4.9.

Figure 4.4 presents the percent frequency distribution of the PSFB doses of all the subjects in 0.5 MED unit intervals. A total of 34.6% of the daily PSFB doses fall between 0.1 - 0.5 MED units, while 27.2% fall between 0.5 - 1.0 MED units. A large proportion (68%) of the subjects' PSFB doses was less than 1 MED unit or 200 J m^{-2} and therefore did not pose a risk of erythema. However, what is more important is that approximately one-third of the PSFB doses constituted a risk of erythema. It is also important to bear in mind that it is unknown whether or not cumulative exposure at

low ultraviolet radiation doses may still contribute towards the development of skin cancer during adulthood.

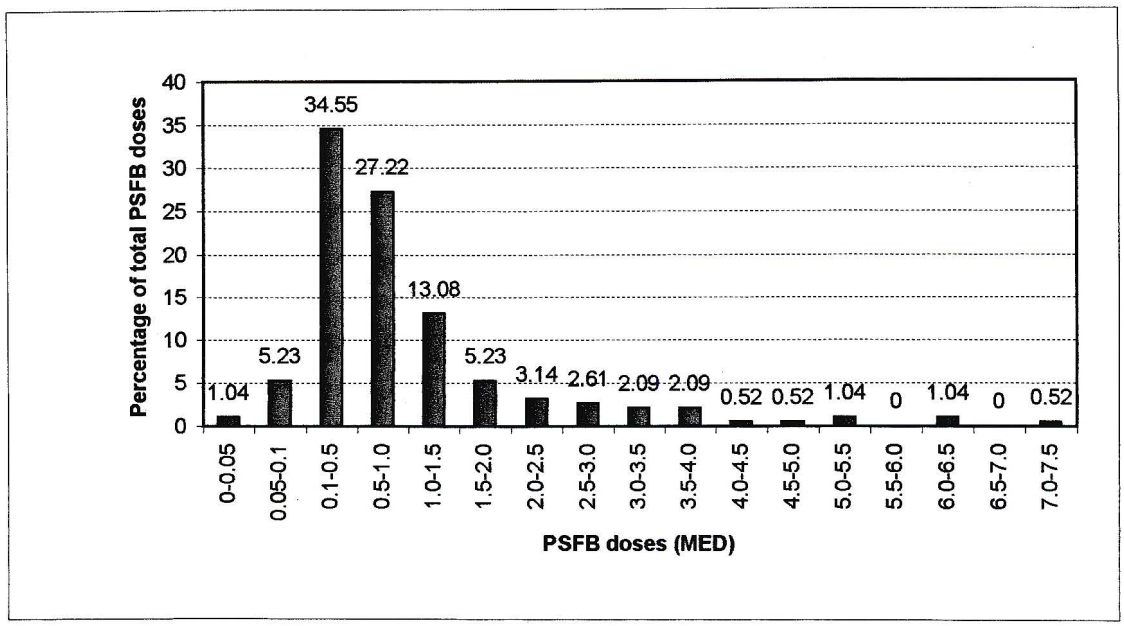


Figure 4.4: Frequency distribution of PSFB for each EUV dose category in MED units of all the subjects

An explanation for the unexpectedly low PSFB doses recorded in this study is sought in the prevailing climatic conditions. Ambient EUV levels were relatively high during the study period (see Section 4.2) and it was therefore expected that the subjects' PSFB doses would have been higher. However, the particular climatic conditions experienced during the week of the study may account for the skewed distribution of the daily PSFB doses towards the lower MED values. Due to high maximum air temperatures (mean of 28.5°C) and high humidity factors (mean of 86.4%) subjects may have tended to avoid direct sunlight and found shade during break times whilst at school. Only while subjects were engaged in outdoor extramural activities and sports such as playing in the garden, swimming, walking home, tennis and golf were they exposed to direct sunlight.

It is important to note that in this study a value of 1 MED unit was regarded as the threshold above which the risk of adverse health effects associated with ultraviolet radiation exposure occurs (Diffey, 1991). However, an EUV daily exposure limit of 30 J m^{-2} (0.15 MED units) is also used in international studies as an indication of a

permissible amount of EUV received by an individual on one day without resulting in any damage to their health (Herlihy *et al.*, 1994). The National Health and Medical Research Council of Australia adopted this limit in accordance with the International Radiation Protection Association's recommended guidelines for occupational exposure to ultraviolet radiation. The mean and median daily PSFB doses for all subjects in this study fell above 0.15 MED units and consequently pose a potential risk according to this daily exposure limit. This limit of 30 J m^{-2}, if received on a horizontal surface in Durban, would be exceeded in approximately two minutes around local noon. The time needed to receive 200 J m^{-2} or 1 MED unit during a similar period on a horizontal surface would be approximately 11 minutes. Ambient EUV levels were therefore significantly high to pose a potential risk to subjects exposed for lengthy periods to the direct solar beam.

Gies *et al.* (1998) conducted a similar ultraviolet radiation dosimetry study in Brisbane, Australia. A total of 112 primary school children, all 12 years of age, wore one PSFB per day, attached to the shoulder, for a two-week period during mid-summer, with one week being during school term and one week during school holidays. The mean total daily ambient EUV in Brisbane was 26.7 MED units and was similar to that experienced in Durban during the study period of 27.12 MED units.

Table 4.6: The median (with 95% range quoted in parentheses) PSFB doses in MED units for children in Brisbane (After: Gies *et al.*, 1998)

	Weekdays	**Weekend**	**Median for all days**
Brisbane boys	4.6 (0.6-7.3)	0.6 (0.2-10.2)	4.2 (0.4-11.5)
Brisbane girls	2.0 (0.5-5.0)	0.7 (0.1-2.8)	2.4 (0.3-8.8)

The results of the study indicate that PSFB doses received by children in Brisbane were higher than those received in Durban (Table 4.6). This may be on account of the positioning of the badge on a more horizontal anatomic site, i.e. the shoulder. The particular climatic conditions, namely the high air temperatures and humidity

experienced during the study period, may also have accounted for the lower doses as discussed earlier.

4.5 The relationship between ambient EUV and individual ultraviolet radiation exposure

Calculating individual ultraviolet radiation dose as a percentage of the daily ambient EUV is a useful means of combining all influencing factors and providing a broader understanding of the relationship between ultraviolet radiation incident upon the earth's surface and that incident upon human beings.

4.5.1 Ultraviolet radiation dose as a percentage of total daily ambient EUV

Table 4.7 shows the mean daily PSFB dose for weekdays and weekend for each age group as a percentage of the total daily ambient EUV measured by the YES UVB-1 pyranometer. The results show that the weekend percentages were greater than the weekday percentages. The 7 - 9 year old subjects received the highest percentage of ambient EUV of 12.1% for weekend days as well as the lowest percentage of ambient EUV of 2.8% for weekdays. The weekday median percentages of ambient EUV are relatively low, particularly compared with the median values of 5 - 6% of the ambient EUV as calculated by Diffey *et al.* (1996).

Table 4.7: The mean, median and 95% range of the daily PSFB doses as a percentage of the total daily ambient EUV for week and weekend days

Age group	Weekday			Weekend		
	Mean	Median	95% range	Mean	Median	95% range
4 – 6 years	4.49	2.03	0.92-26.71	7.91	4.47	1.04-31.23
7 – 9 years	2.84	2.34	0.63-13.09	12.18	6.31	1.89-51.24
13 – 14 years	2.91	1.86	0.48-12.04	9.84	6.51	1.41-48.04

The weekend median percentages of ambient EUV are higher than those percentages by Diffey *et al.* (1996). The average percentage of total daily ambient EUV for all subjects for all days of the week was 4.58%, with a median of 2.1% and a 95% range of 1.3 - 51.2%. The median value for this study was lower than that noted by Gies *et*

al. (1998) of 4.3 - 8.6% and this may be on account of the times spent outdoors by the children and adolescents in Durban being mostly in the shade compared to Brisbane

Figure 4.5 indicates the frequency distribution of the daily PSFB doses as a percentage of the total daily ambient EUV for all subjects on all days of the study. A maximum of 52 PSFB doses were calculated as being between 1 - 1.9% of the total daily ambient EUV. The graph does not exhibit a normal distribution and is skewed towards the lower percentages with 83.76% of the PSFB doses lying below 9% of the total daily ambient EUV.

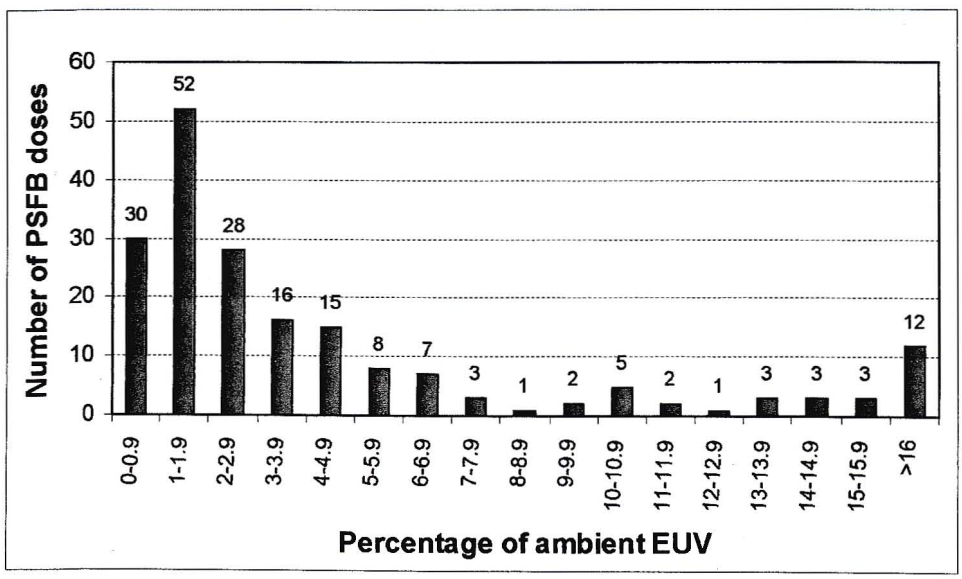


Figure 4.5: Frequency distribution of the subjects' PSFB doses as percentages of the total daily ambient EUV

The 95% range (Table 4.7) indicates the variability amongst the subjects' PSFB doses, since there were some subjects who received as much as 50% of the total daily ambient EUV. This substantiates the finding that the daily EUV doses of children and adolescents in Durban cannot be generalised, as they do not act as a homogenous group, thus emphasising the importance of human behaviour in influencing human ultraviolet radiation exposure.

4.5.2 Ultraviolet radiation dose as a percentage of the ambient EUV for the exact exposure periods

To estimate the maximum potential daily EUV dose of each subject, the YES UVB-1 pyranometer measurements were used in accordance with the times spent outdoors stipulated in each subject's personal ultraviolet radiation journal. In this manner, the highest possible EUV dose as received on a horizontal surface for the subject's exposure periods was determined. The factor of timing of exposure was eliminated allowing for a closer understanding of the relationship between ambient EUV and human exposure by taking into consideration shading. The mean PSFB dose as a percentage of the ambient EUV for the exact periods of exposure was 18.6%, with a median of 11.5% and a 95% range of 5.9 - 230.6%. The obviously inaccurate upper value of the 95% range highlights one of the problems encountered when making use of retrospective journal keeping by children or adolescents. In this instance, certain subjects underestimated their exposure period, i.e. the time spent outdoors for a particular activity.

In order to determine the influence of making use of shade as an ultraviolet radiation protection mechanism in comparison to being in direct sunlight during ultraviolet radiation exposure periods, two scenarios were investigated. The daily PSFB doses for days when subjects spent each of their indicated exposure periods outdoors in the sun were plotted against an estimated EUV dose using the total EUV dose measured by the YES UVB-1 pyranometer for the exact periods of ultraviolet radiation exposure (Figure 4.6). Similarly, the daily PSFB doses for the days on which subjects spent each of their indicated times outdoors in the shade were plotted against an estimated EUV dose that was weighted by 0.5 in accordance with Kimlin *et al.* (2000) (Figure 4.7). The gradients of the best fit straight lines were 0.2745 for all sun and 0.1815 for all shade daily ultraviolet radiation exposures. It is interesting to note that the mean PSFB dose as a percentage of the ambient EUV for the exact periods of exposure was 18.6% and that when considering only all shade exposures on any particular day, the mean PSFB dose as a percentage of the estimated EUV dose was 18.2%. This may serve to illustrate that the majority of the subjects' exposures were in the shade.

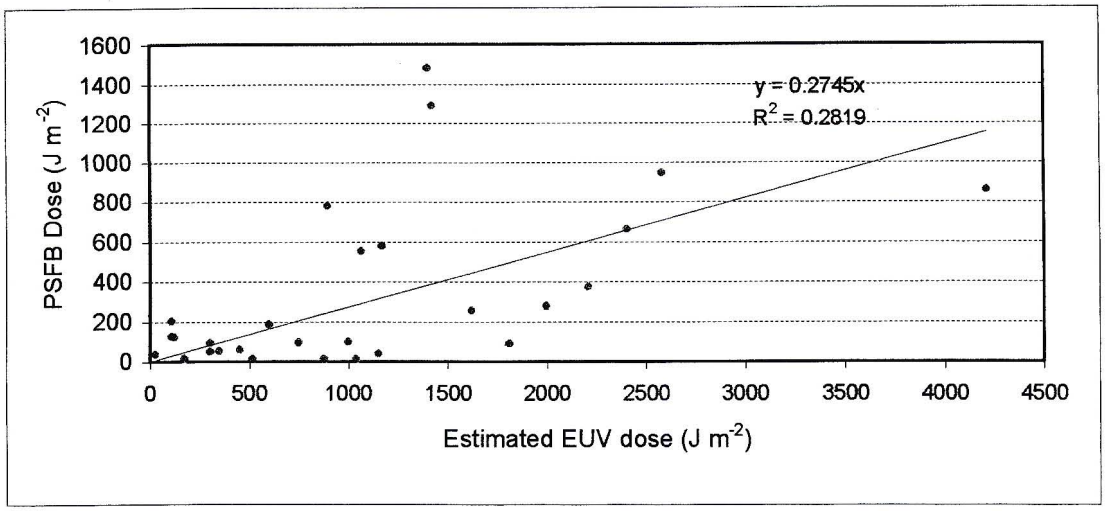


Figure 4.6: PSFB dose versus estimated EUV dose for all sun exposures on any day

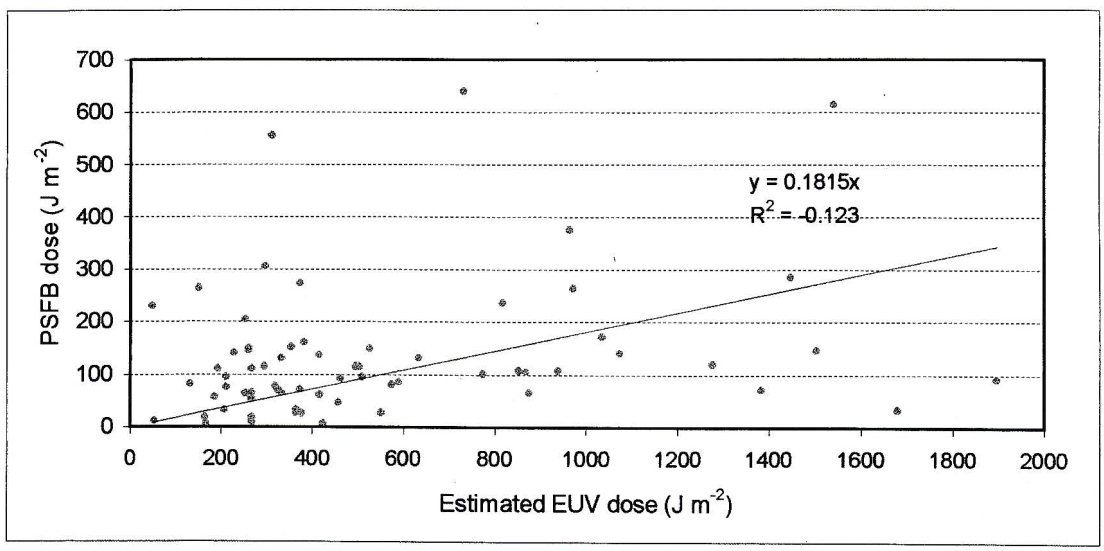


Figure 4.7: PSFB dose versus estimated EUV dose for all shade exposures on any day

4.5.3 Ultraviolet radiation dose as a percentage of the theoretical EUV dose

A more sophisticated approach was applied in order to eliminate factors of varying ambient EUV, shading conditions and orientation of the anatomic site under investigation. The calculation applied was provided in Equation 3.3 in Section 3.9. The mean PSFB dose as a percentage of this theoretical EUV dose was 64.6%, with a median of 41.4% and a 95% range of 10.2 - 399.9%. The reason that the upper value is greater than 100% is possibly due to inaccurate records noted by the subjects. It was also likely on account of some of the PSFBs having been laid on a horizontal surface

during swimming periods, thereby receiving an EUV dose resembling the ambient EUV conditions during that period of exposure.

There is clearly not a direct correlation between the PSFB dose and the theoretical EUV dose due to a number of assumptions. The factor used to weight the EUV dose for shade or sun conditions, i.e. the activity index (AI) was assumed to be 0.5 for shade conditions (Kimlin *et al.*, 2000) and 1 for sun conditions. This may have underestimated or overestimated the weighting for shade conditions since the influence of shade on ultraviolet radiation is highly variable and might not warrant the use of a single factor.

The amount of ultraviolet radiation received by a particular anatomic site or the exposure ratio (ER) of 0.44 may have been too high for the lapel site and consequently overestimated the EUV dose. However, application of a theoretical model allows for a crude elimination of variables such as time of day, shading and anatomic orientation and therefore illustrates the influence of human movement and behaviour on the PSFB dose received by the subject.

Figure 4.8 presents the theoretical EUV dose, calculated according to Equation 3.3 in Section 3.9 and the corresponding PSFB dose for all subjects during the study period. Most of the PSFB doses are less than the theoretical EUV doses suggesting that the AI and ER may have been too high or the journal entries were inaccurate. The use of this equation allows for the inclusion of more parameters to describe the relationship between ambient EUV and individual EUV dose such that the more parameters used, the better the fit between the two doses. Significant factors such as random movement, direction towards the direct solar beam, e.g. facing or turning away from the sun, and positioning of the body, e.g. assuming a standing or seated position, all influence the fraction of ambient EUV received by an individual to different anatomic sites.

4.6 Annual ambient EUV variation and human ultraviolet radiation exposure

In order to provide an estimate of the relationship between annual ambient EUV levels and the daily EUV dose of children and adolescents during one year in Durban,

the mean daily PSFB dose as a percentage of the total daily ambient EUV (4.58%), was used in conjunction with the total daily EUV (MED units) for 2000 (Figure 4.2). The factor of 0.0458 was then used to determine the annual potential daily EUV dose of the subjects (Figure 4.9). The use of this weighting does not infer that an individual spends all day outdoors exposed to the direct solar beam and takes into consideration similar exposure patterns as discussed for the subjects involved in this study.

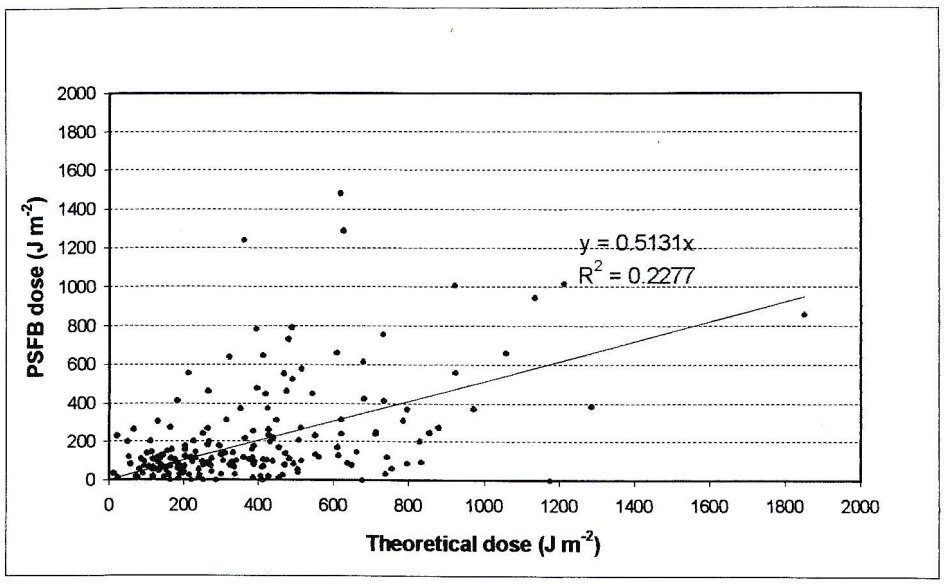


Figure 4.8: Comparison between the theoretical EUV dose and PSFB dose

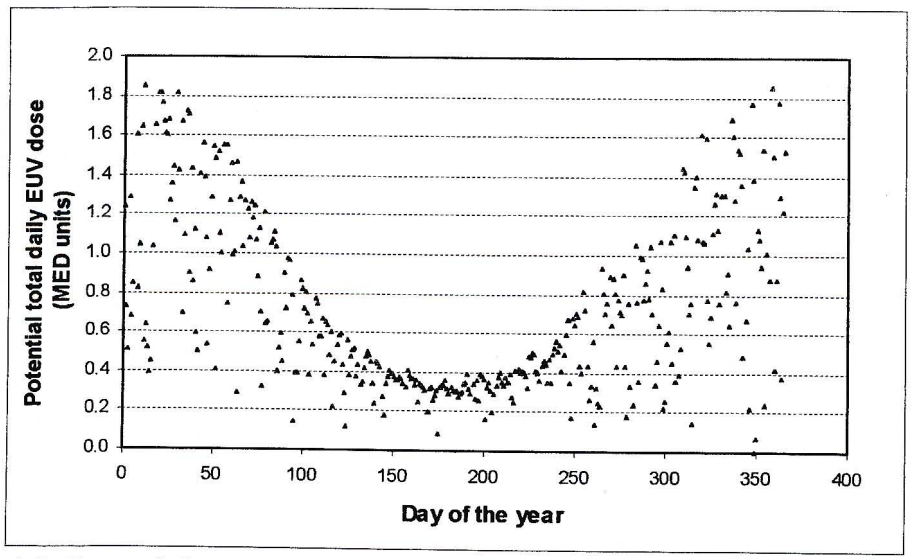


Figure 4.9: Potential total daily EUV dose which children and adolescents may receive during one year in Durban

During the summer months of December, January and February, total daily MED values extend up to approximately 1.8 MED units while winter values for June, July and August fall between 0 - 0.5 MED units. The weighting used, i.e. 0.0458, was an average for all 30 subjects over all 7 days of the study period and may not be representative of those subjects who received relatively high PSFB doses. Therefore, the use of 0.0458 may have underestimated the total daily EUV doses, throughout the year, for those subjects with consistently higher PSFB doses.

Extended periods of ultraviolet radiation exposure are known to have adverse health consequences including the onset of erythema. The time before it becomes apparent on the surface of the skin depends on the skin type and the intensity of the erythemal ultraviolet radiation dose. Diffey (pers. comm., 2001) indicates the number of MED units required to induce minimal, painful and severe erythema for skin types I, II, III and IV (Table 4.8). The darker the skin type the greater the EUV dose required to induce various stages of erythema. For example, an individual with a skin type of III requires 1.5 MED units of EUV to experience minimal erythema and 7.5 MED units to experience severe erythema.

Table 4.8: MED units required to induce minimal, painful and severe erythema in skin types I, II, III and IV (Adapted from: Diffey, pers. comm., 2001)

Skin type	Minimal erythema	Painful erythema	Severe erythema
I	0.75	2.25	3.75
II	1	3	5
III	1.5	4.5	7.5
IV	2	6	10

By superimposing the MED values for each skin type required to induce minimal erythema, onto the annual variation in total daily EUV doses, there are 139 days when individuals with a light skin type of I are likely to experience minimal erythema and 97 days for individuals with a skin type of II (Figure 4.10). Individuals with medium skin colour with a skin type of III have 32 days during the year when they are likely to experience minimal erythema.

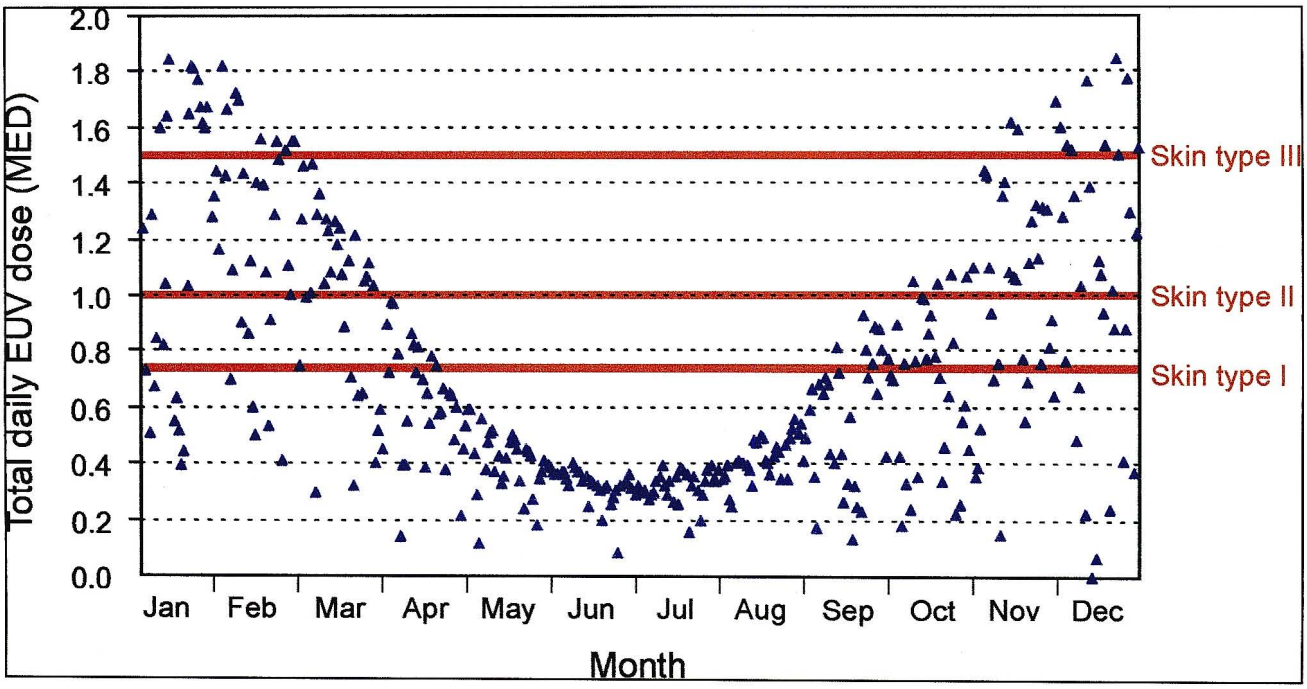


Figure 4.10: Potential total daily EUV dose and indication of minimal erythema

The majority of the days that minimal erythemal is likely to be experienced by these three skin types are during the summer months when ambient EUV levels are relatively high. According to Figure 4.10, there are no days during the year when individuals with a skin type of IV are likely to experience minimal erythema. However, this depends on the nature of their exposure patterns, where excessive ultraviolet radiation exposure may result in erythema. Although cumulative EUV doses of this nature may produce other health risks, clearly it is not immediately harmful to an individual with a skin type of II or III spending on average 2 hours outdoors intermittently and not necessarily around local noon.

The relationship between ambient EUV levels and human exposure is undoubtedly complicated and contains inherent complexities making it difficult to provide generalisations that represent the uniqueness of individual behaviour, particularly in the South African context. There is clearly a direct need for increased ultraviolet radiation awareness amongst younger generations, particularly in view of the acute risk of erythema and the chronic risk of MMSC.

Based on the variability encountered throughout the study it is difficult to provide an EUV limit for children and adolescents residing in Durban that could act as a

threshold EUV dose to prevent the occurrence of MMSC during adulthood. It is recommended that children and adolescents are made aware of the different risks associated with ultraviolet radiation exposure and then informed of their skin types to understand the value of using ultraviolet radiation protective mechanisms during their outdoor activities and as part of routine behaviour patterns.

4.7 Ultraviolet radiation dose as a function of various factors

The following section will consider the relationship between the subjects' daily PSFB doses and five variables including age, gender, skin type, behaviour and activity in order to determine which variable plays the greatest role in determining individual ultraviolet radiation dose.

4.7.1 Ultraviolet radiation dose as a function of age

Analysis of the daily PSFB doses as a function of age showed that the youngest age group (4 - 6 years) received the highest mean PSFB dose of 1.08 MED units although there was little difference in the mean PSFB doses of the three age groups (Table 4.9). Application of a non-parametric analysis of variance confirmed that there was no statistically significant difference at a 95% confidence level between the daily PSFB doses of the three age groups. The 95% ranges showed similar lower limits, however, the upper limits differed markedly. Subjects aged 7 - 9 years experienced the highest upper limit of 7.22 MED units. Analysis of the results as a function of day of the week showed that this was due to a particularly large 95% range over the weekend for this age group (Table 4.10). It is also noted from Table 4.10 that there is a lack of consistency in the age group receiving the highest PSFB dose on any particular day as reflected in both the mean and median values. In each age group there were individuals who received markedly greater or lesser PSFB doses than their peers and this affected the mean results. A subject who spent a large proportion of time outdoors or a short period of time during a time of day when ambient EUV levels were high received a considerably higher PSFB dose thereby shifting the group average towards a higher value.

Table 4.9: The mean, median and 95% range of the daily PSFB doses (MED units) for each age group over the 7 day study period

Age group	Mean	Median	95% range
4 – 6 years	1.08	0.58	0.20-6.04
7 – 9 years	1.03	0.65	0.24-7.22
13 – 14 years	1.00	0.54	0.16-4.96

Table 4.10: The mean, median and 95% range of daily PSFB doses (MED units) for age groups (a) 4 – 6 years, (b) 7 – 9 years and (c) 13 – 14 years or as a function of day of the week

(a)

Ages 4-6	Day of the week						
	1	2	3	4	5	6	7
Mean	1.07	1.00	1.94	0.71	0.37	0.88	0.52
Median	0.58	0.76	0.64	0.52	0.34	0.59	0.21
95% range	0.06-2.72	0.12-3.12	0.28-6.04	0.05-2.01	0.02-0.87	0.07-2.99	0.08-3.22

(b)

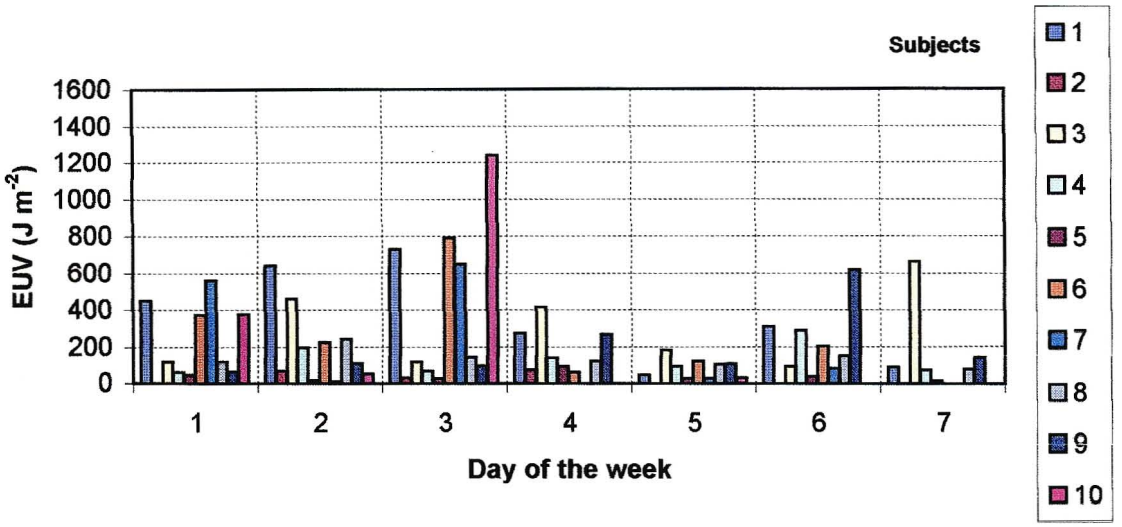
Ages 7-9	Day of the week						
	1	2	3	4	5	6	7
Mean	0.78	0.88	0.53	0.78	0.60	1.22	1.91
Median	0.83	0.74	0.54	0.52	0.54	0.79	0.71
95% range	0.03-1.51	0.19-2.69	0.19-1.00	0.16-2.71	0.35-1.26	0.12-4.91	0.18-7.22

(c)

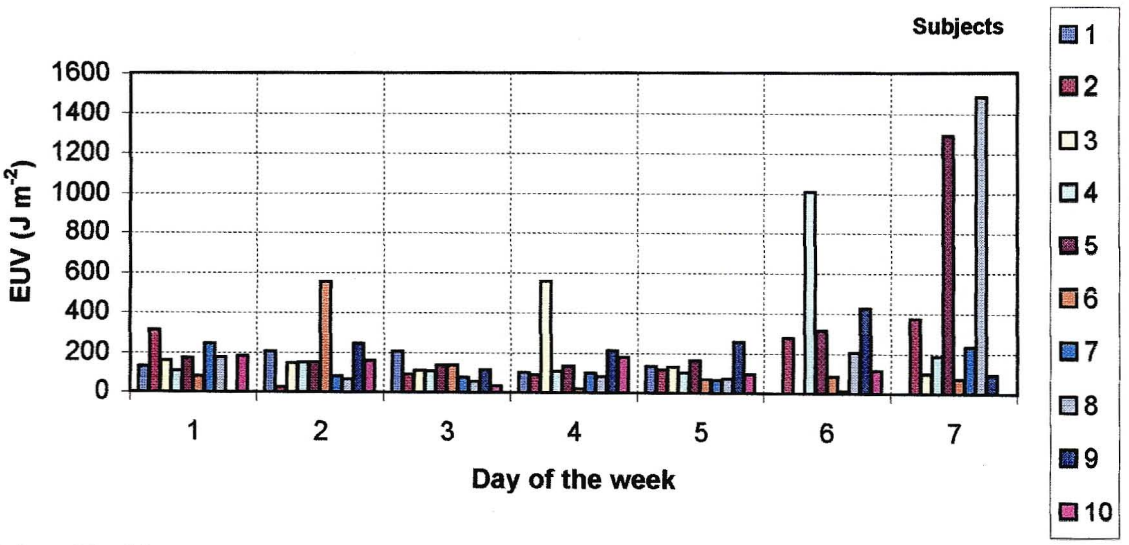
Ages 13-14	Day of the week						
	1	2	3	4	5	6	7
Mean	1.34	0.41	0.88	0.53	0.62	1.00	1.75
Median	1.26	0.38	0.56	0.38	0.51	0.50	0.58
95% range	0.23-3.67	0.06-1.05	0.30-2.34	0.12-1.53	0.03-1.31	0.11-4.6	0.12-4.96

The variability of the daily PSFB doses within each age group for each day of the week is illustrated in Figure 4.11. It is noteworthy that the variability amongst children and adolescents of formal school going age, i.e. 7 - 9 and 13 - 14 years, is less during the weekdays than that of the 4 - 6 year age group, most likely as a result of the more structured school day in the two former age groups.

(a) Ages 4 - 6 years



(b) Ages 7 - 9 years



(c) Ages 13 - 14 years

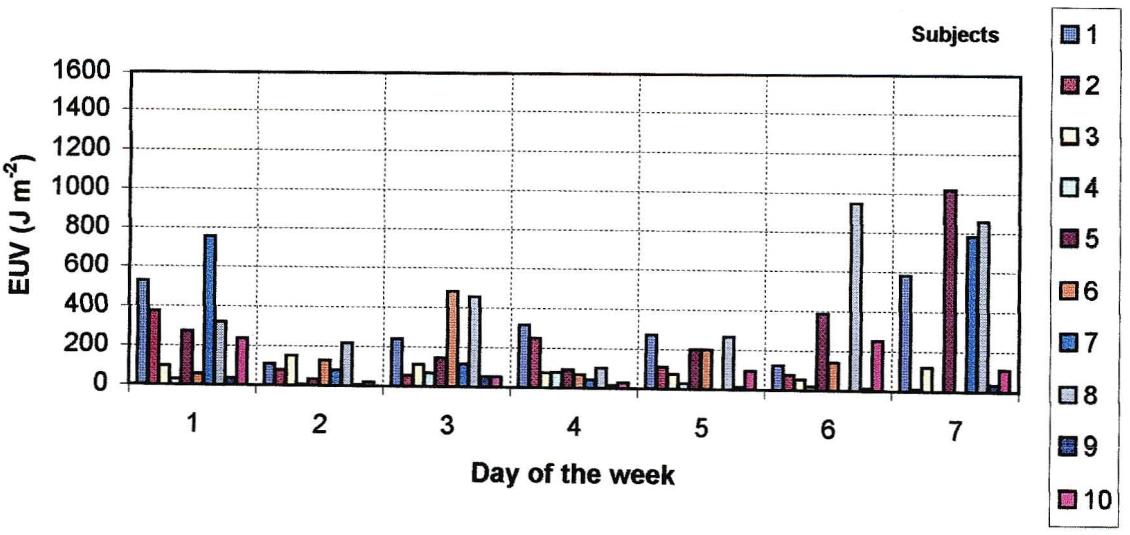
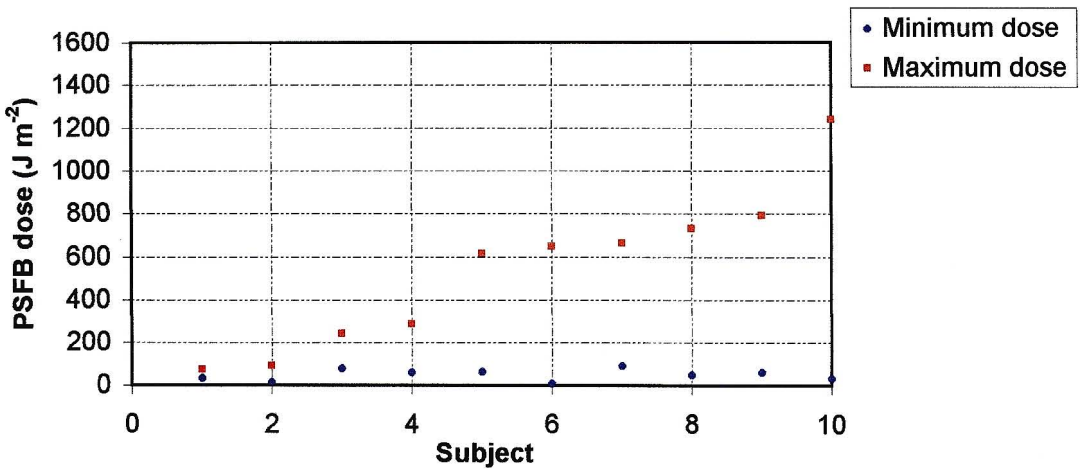
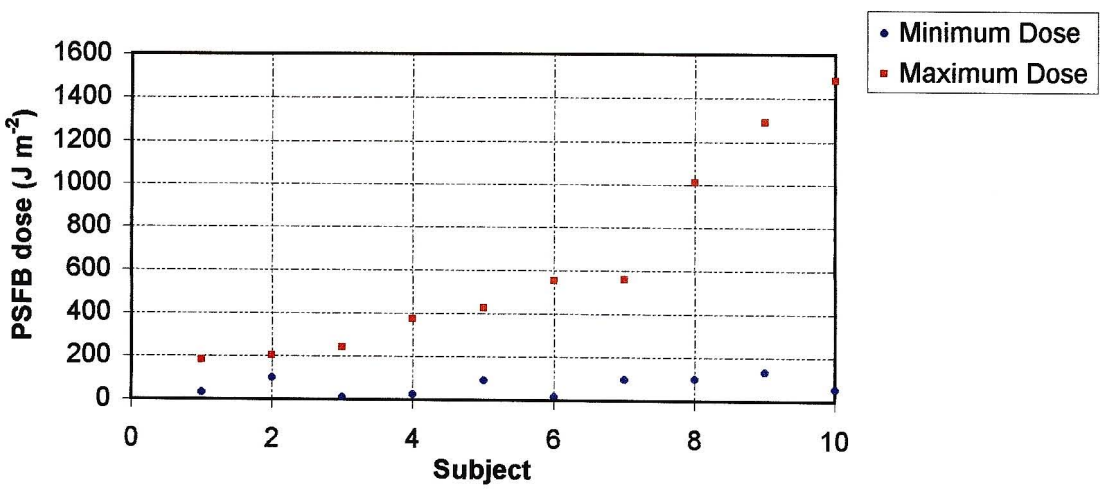


Figure 4.11: PSFB doses (J m^{-2}) of subjects within each age group as a function of day of the week

(a) Ages 4 - 6 years



(b) Ages 7 - 9 years



(c) Ages 13 - 14 years

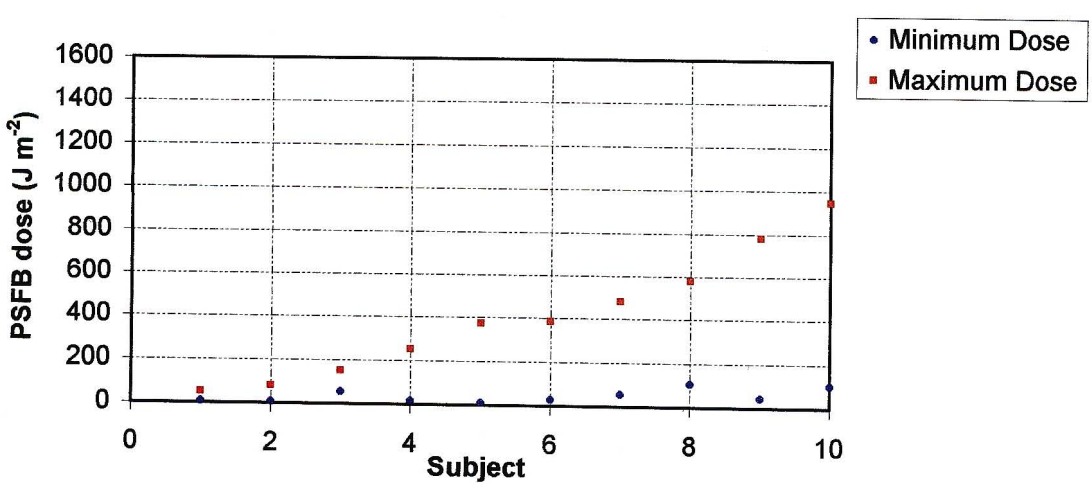


Figure 4.12: Minimum and maximum PSFB dose (J m^{-2}) for each subject recorded during the study period as a function of age group. Values are ranked by maximum PSFB dose.

Over the weekend when these age groups are able to determine their own behaviour, their variability is far greater and exceeds that of the 4 - 6 year age group.

The large variability between individuals in each age group is also visible in Figure 4.12. Ranked by maximum PSFB doses, it is evident that the minimum PSFB dose received by a subject of any age on any day varied little, being equivalent to or less than 200 J m^{-2} (1 MED unit). However, the maximum PSFB doses varied greatly with values reaching up to 1500 J m^{-2} or 7.5 MED units for the 7 - 9 year age group. The daily PSFB doses for adolescents were all less than 1000 J m^{-2} or 5 MED units suggesting that children of pre-school and pre-primary school going age receive potentially higher daily PSFB doses than adolescents attending high school. A similar finding was noted by Diffey *et al.* (1996) for children between the ages of 9 -10 years and 14 - 15 years in a study conducted in England.

Whilst it is evident that children below 13 years do have the highest daily PSFB doses in this study, it is difficult to support a conclusive statement about a relationship between age and PSFB dose with the data at hand. Figure 4.13 endorses the variability noted earlier and shows that there is no clear dependence of PSFB dose on age.

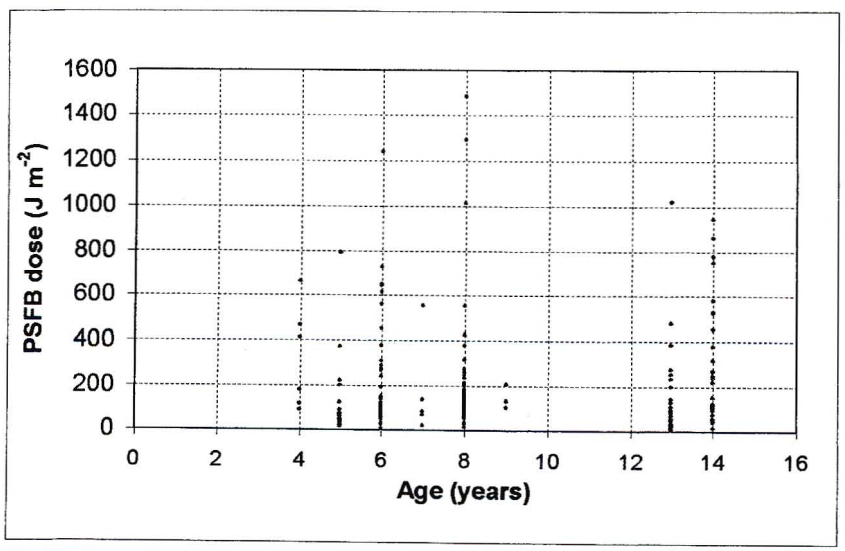


Figure 4.13: The relationship between each subject's daily PSFB dose and their age for the duration of the study period

Sun-safe strategies should therefore be implemented in line with the precautionary principle and should target children of pre-school and primary school-going age yet

also filtering through all other levels of schooling and the general public. Results indicate that younger children received a fair proportion of their weekly EUV doses during weekdays and therefore communication and safe-sun behaviour should be implemented in the school teaching system to emphasise the need for increased ultraviolet radiation protection measures at an early age.

4.7.2 Ultraviolet radiation dose as a function of gender

A comparison between the mean and median daily PSFB doses of male and female subjects showed that male subjects generally received higher PSFB doses than female subjects (Table 4.11). The 95% range for males extended to 7.22 MED units compared to 6.28 MED units for females. However, application of the Wilcoxon 2-sample test found that there was a statistically significant difference at a 95% confidence level between the daily PSFB doses of male and female subjects, where male subjects tended to receive higher daily PSFB doses.

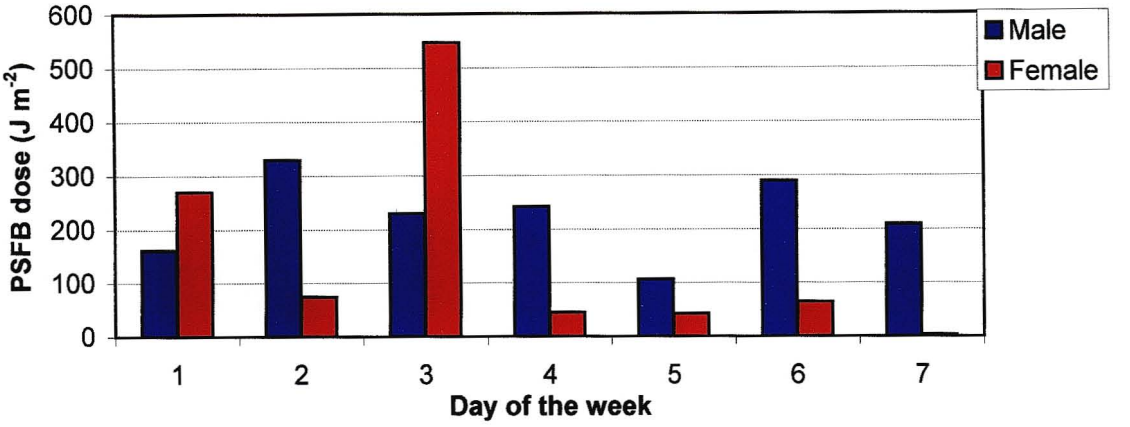
Table 4.11: Comparison of the mean, median and 95% range of the daily PSFB doses (MED units) for male and female subjects

	Mean	Median	95% range
Male	1.15	0.68	0.23-7.22
Female	0.92	0.51	0.19-6.28

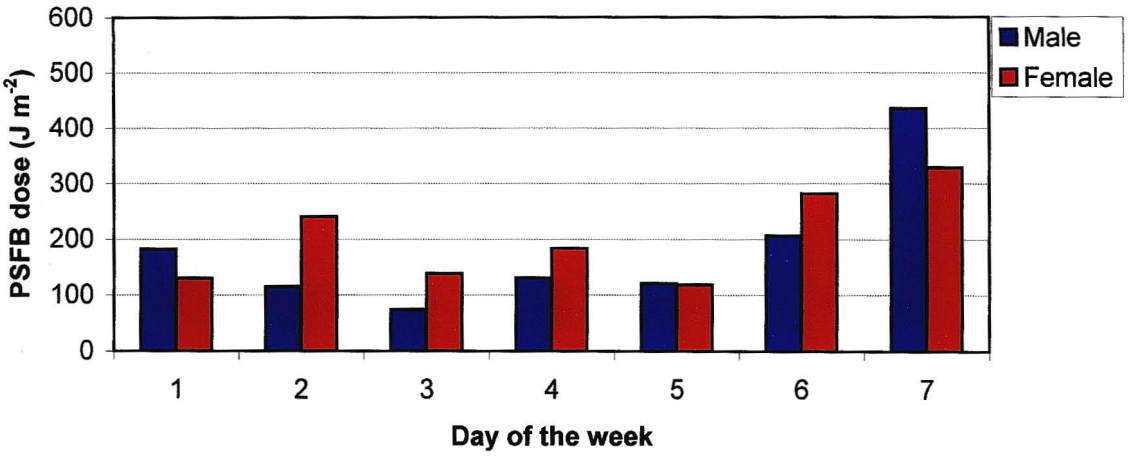
Figures 4.14 and 4.15 present the mean and median PSFB doses for male and female subjects for every day of the week for each age group. The results indicate considerable variability and do not allow for visual confirmation of the results provided in Table 4.11 for all subjects, irrespective of age. However, it would appear that the weekend mean and median PSFB doses were always greater for males than for females. This may be on account of males participating in more outdoor activities and thus spending longer periods of time outdoors on weekend days.

The most recent cancer statistics for South Africa (www.cansa.co.za) for the period 1993 - 1995 show that for light-skinned males, 50.8% of all cancer cases are skin cancers including SCC, BCC and MMSC.

(a) Ages 4 - 6 years



(b) Ages 7 - 9 years



(c) Ages 13 - 14 years

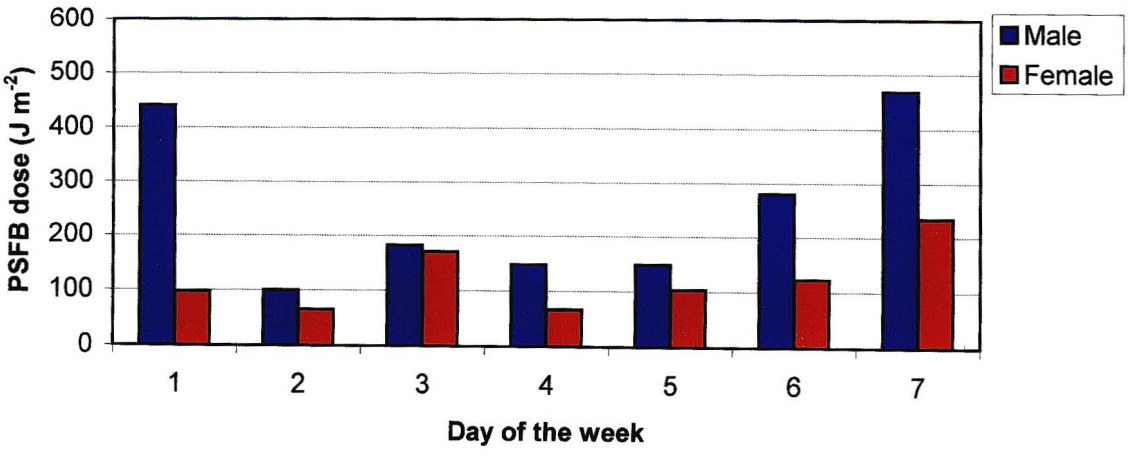
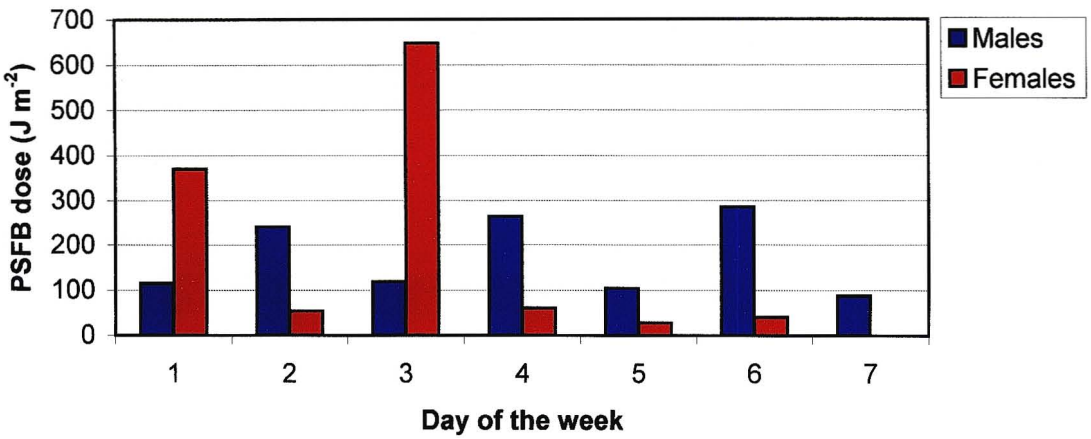
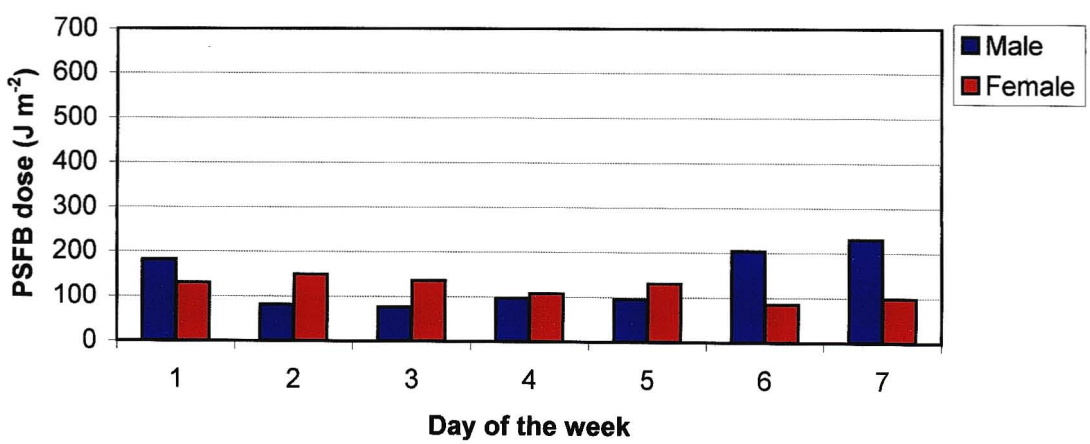


Figure 4.14: Comparison between the mean PSFB doses (J m^{-2}) of male and female subjects for each age group.

(a) Ages 4 - 6 years



(b) Ages 7 - 9 years



(c) Ages 13 - 14 years

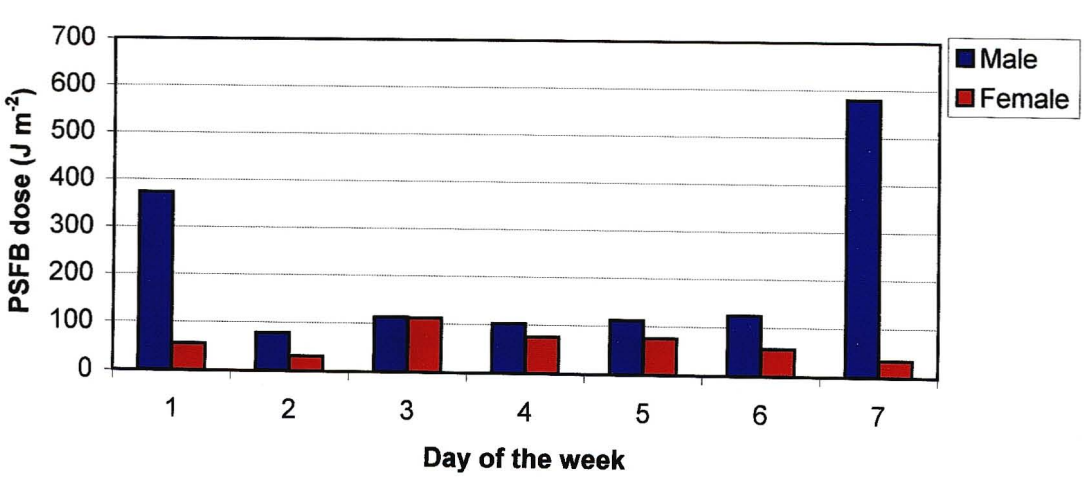


Figure 4.15: Comparison between the median PSFB doses (J m^{-2}) of male and female subjects for each age group.

The number of skin cancer cases, as a percentage of the total number of cancer cases for light-skinned females is 41.5%, 9.2% less than that for males. Evidently, the incidence of skin cancer is higher amongst males than females. The results of this study suggest that males tend to receive higher daily PSFB doses than females and considering the hypothesis that ultraviolet radiation exposure is one of the factors inducing skin cancer, males may be more susceptible to this risk than females.

4.7.3 Ultraviolet radiation dose as a function of skin type

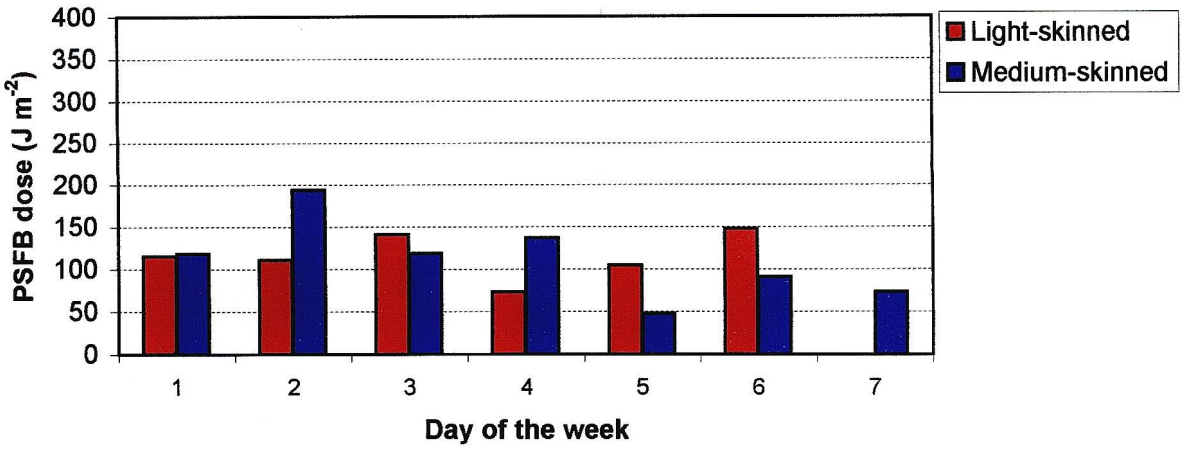
Table 4.12 shows the daily PSFB doses for light-skinned subjects (skin types I and II) and medium-skinned subjects (skin types III, IV and V). Although the mean PSFB dose for medium-skinned subjects was 0.08 MED units higher than that for light-skinned subjects, the median PSFB dose was 0.15 MED units less than the light-skinned subjects' median PSFB doses. Application of the Wilcoxon 2-sample test showed that there was no statistically significant difference at a 95% confidence level between the light-skinned and medium-skinned subjects' daily PSFB doses.

Table 4.12: The mean, median and 95% range of the daily PSFB doses for light-skinned and medium-skinned subjects

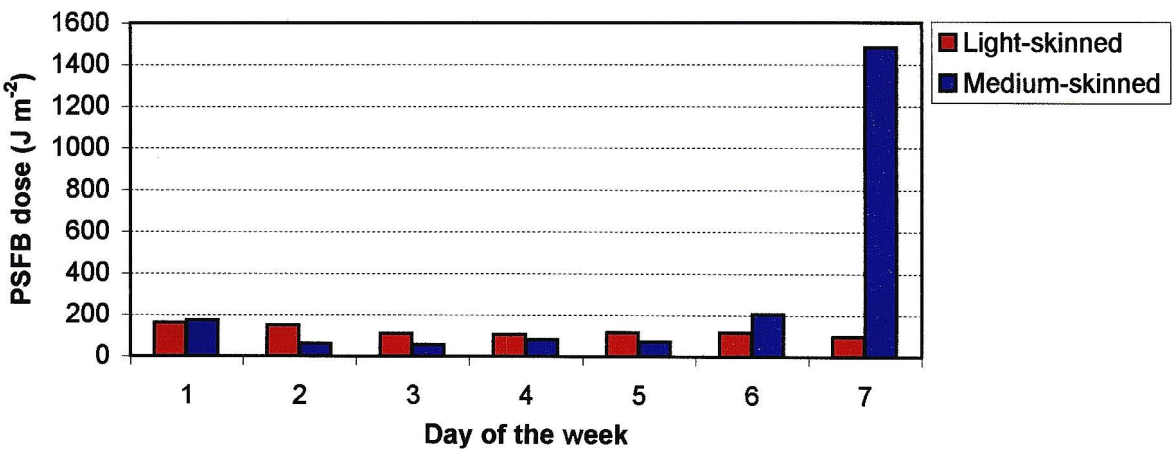
	Light-skinned subjects	Medium-skinned subjects
Mean	1.00	1.10
Median	0.63	0.47
95% range	0.22-7.22	0.19-6.29

Figure 4.16 compares the median PSFB doses (J m^{-2}) of light and medium-skinned subjects of each age group as a function of day of the week. There is no consistent pattern or trend in the results, indicating that a factor other than skin type is responsible for the variability that exists in the results. It is noteworthy that the 95% range of PSFB doses extends above 1 MED unit for both skin categories (Table 4.12). Medium-skinned subjects require a greater number of MED units to induce erythema than light-skinned subjects. The values range between 1.5 - 7.5 MED units for minimal to severe erythema respectively (Diffey, pers. comm., 2001).

(a) Ages 4 - 6 years



(b) Ages 7 - 9 years



(c) Ages 13 - 14 years

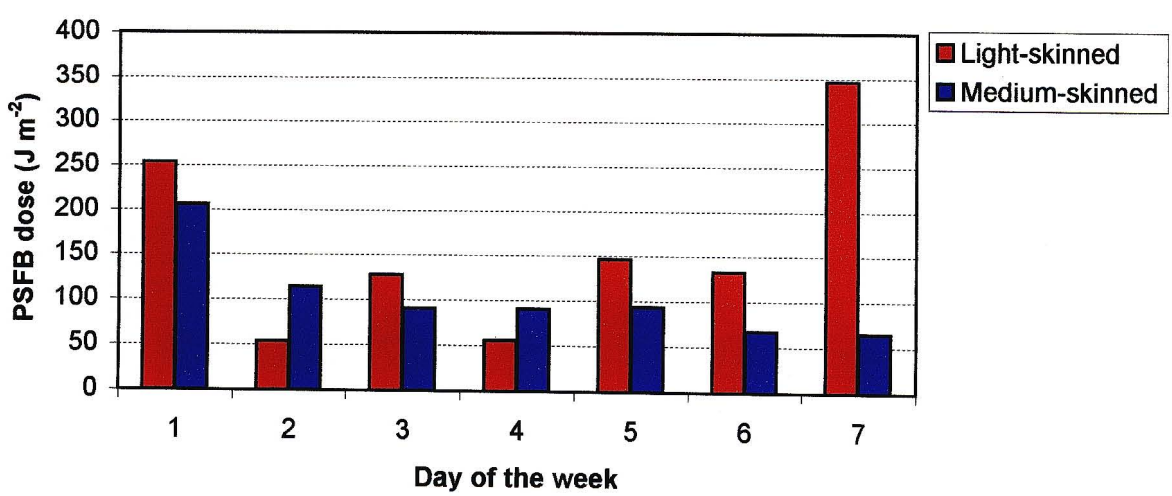


Figure 4.16: Comparison between the median PSFB doses (J m^{-2}) of light- and medium-skinned subjects

Evidently, there were certain light and medium-skinned subjects who received sufficiently high PSFB doses during the week to induce erythema on more than one day. This may have adverse health implications for all skin types in terms of the cumulative nature of intermittent EUV exposure. Six of the subjects had relatively fair skin, blue or light brown eye colour and blonde or red hair (Table 4.4). Five of these subjects also had at least two days during the week when their daily PSFB doses ranged between 2.77 - 3.90 MED units. Owing to the fair skin types of these subjects, it is likely that they experienced erythema at least once during the study period. More importantly, the daily medium-high PSFB doses received by these subjects may have implications for the induction of skin cancer later in life (Gies *et al.*, 1995; and Moise *et al.*, 1999a).

4.7.4 Role of sunscreen

Analysis of the personal ultraviolet radiation journals with respect to sunscreen usage suggested that most children and adolescents do not use sunscreen as a regular part of their daily routine. Only 14 subjects applied sunscreen at least once on one of the days of the study (Table 4.13).

Table 4.13: Subjects who applied sunscreen at least once on at least one day during the study period

Age group	Number of subjects	Percentage of total subjects
4 – 6 years	3	10%
7 – 9 years	6	20%
13 – 14 years	5	17 %

One of the younger subjects (age 6) had sunscreen applied to his face and arms by his mother every morning. The remaining sunscreen applications by the other subjects were mostly on weekends and during recreational or sporting activities, i.e. golf, swimming, tennis, horse riding and cricket, after school during the week. Of the 210 person-days, there were only 32 days (15%) on which a subject applied sunscreen.

It should be noted that the EUV dose received by the PSFB relates the highest potential amount of ultraviolet radiation that could conceivably be received by that particular anatomic site and did not take into account any intermediate absorbing surface, i.e. clothing fabrics. Local climatic conditions in Durban result in school uniforms being made out of lightweight cotton with short sleeves. This fabric may offer some protection against ultraviolet radiation to the underlying skin surface at the lapel site. Exposed anatomic sites such as the hands, forearms and face are likely to have received a similar EUV dose to that received by the PSFB had it been attached to one of those anatomic sites.

4.8 Ultraviolet radiation dose as a function of behaviour

Examination of the subjects' personal ultraviolet radiation exposure journals permitted an analysis of the behaviour patterns of the subjects on a daily basis. Generally there was good agreement between the records kept by the subjects and the corresponding PSFB dose for that particular day. The method of self-report and memory recall in keeping a personal journal has inherent weaknesses. To minimise the inaccuracy of the memory-recall technique, subjects were required to complete the journal on a daily basis. Certain subjects did not complete the journal at all, while others omitted activity details or provided partially complete information. A means of eradicating these weaknesses may have been to use a simple timeline instead of a journal to record daily activities. It also became apparent after the study that additional information should have been collected on local shading environments and the use of ultraviolet radiation protective mechanisms such as hats. Notwithstanding these shortcomings the analysis of ultraviolet radiation dose as a function of behaviour has revealed interesting results.

In view of the incomplete nature of some of the journals, various assumptions were necessary during the analysis of the information. These included:

- Where subjects indicated that they were outdoors but did not state whether they were in the sun or the shade, it was assumed that they were in the shade.

- Riding in a motorcar was regarded as an 'indoor environment' since window glass is known to reduce UVB (Tevini, 1993) by acting as a barrier to some of the shorter ultraviolet wavelengths thereby providing some ultraviolet radiation protection (Parisi and Kimlin, 2000). Parisi and Wong (1999) found that the level of UVB is substantially reduced by automobile glass while UVA is less affected and may penetrate the glass. Due to the complexity of the factors involved including the ultraviolet radiation transmission ability of glass, the location of the subject in relation to the window and the time of day when travelling, the car environment was noted as being 'indoors'.

- Participating in an extra-mural activity such as cricket, tennis, swimming, golf and horse riding was assumed to be undertaken in an 'outdoor environment' in the sun unless otherwise stated by the subject.

These assumptions were applied for all subjects in order to ensure consistency and allow for the investigation of behaviour aspects in relation to their daily PSFB doses and ultraviolet radiation exposure patterns.

4.8.1 Ultraviolet radiation exposure patterns: timing and duration

Analysis of the personal ultraviolet radiation exposure journals in terms of the timing and duration of each activity undertaken by the subject was conducted in order to determine the time of day and exposure durations for when subjects were outdoors. Figure 4.17 illustrates the hourly periods during which subjects were most frequently outdoors and consequently exposed to EUV. The greatest number of ultraviolet radiation exposures was recorded between approximately 10:00 - 11:00. This corresponds with the first tea break at most schools when learners are permitted to spend time outdoors. The second highest number of ultraviolet radiation exposure periods was recorded between 12:00 - 13:00 that corresponds with the lunch break in most schools. Both these time intervals fall within the identified period of the day when ambient EUV is relatively high, i.e. between 10:00 and 15:00 (Figure 4.1). Therefore, the potential PSFB doses of subjects exposed during these periods may be high if other factors such as shading conditions and orientation of the anatomic site to the direct solar beam are not taken into consideration. The number of ultraviolet

radiation exposures was relatively constant during the afternoon compared with the morning exposures when the greater variability was related to the timing of school break times.

The ambient EUV was calculated for the exposure periods when subjects were outdoors during break times (Table 4.14). During these times, subjects were exposed to an ambient EUV dose of between 29.18 - 32.03% of the total daily ambient EUV. This is a relatively large proportion of the total daily ambient EUV, although less than the value (47%) calculated by Moise *et al.* (1999a) in a similar study and most likely on account of the break times falling within two hours around solar noon in this latter study.

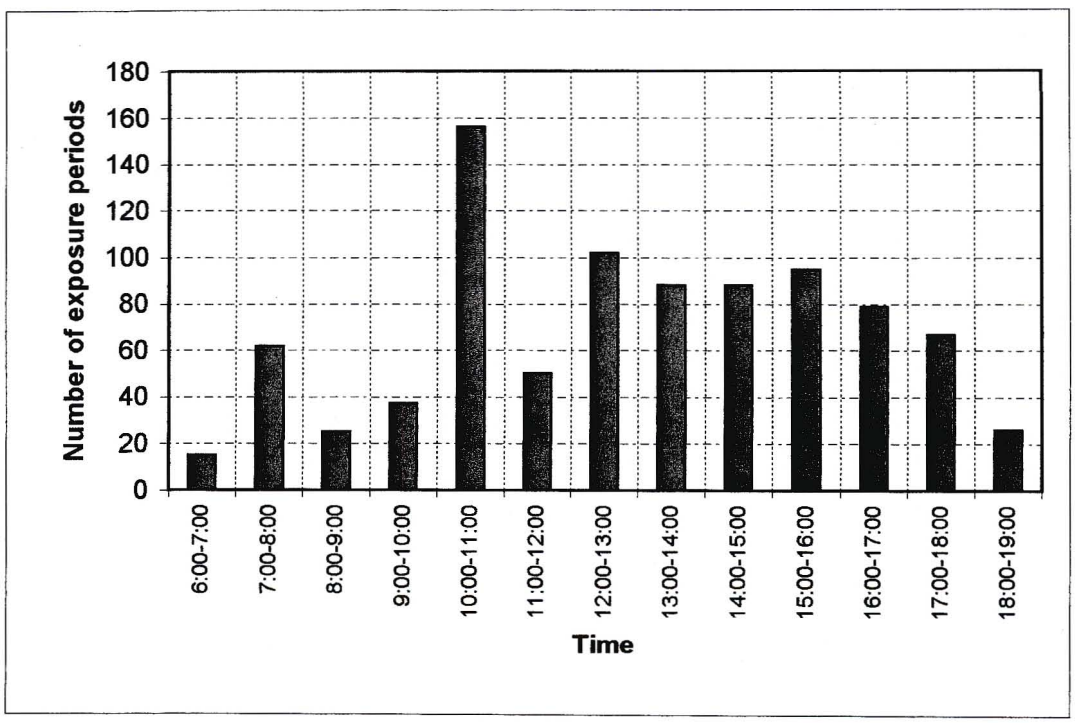


Figure 4.17: Frequency of ultraviolet radiation exposure periods of all subjects during the study period

Table 4.15 shows the length of time spent outdoors for each age group for each day of the week. The overall mean is 2.3 hours per day which compares well with a similar study conducted by Gies *et al.* (1998) who found that Australian children spend an average of 2.2 hours outdoors per day during school terms. This time outdoors is seldom experienced all at once, instead, intermittent exposure periods are

accumulated to obtain a daily total of approximately two hours. Although a relatively small fraction of the day, the timing of the exposure periods, indicated in Figure 4.17, is critical in determining the intensity and severity of the PSFB dose received by the subject.

Table 4.14: Subjects' school break times and the calculated ambient EUV dose (MED units) for these periods

Day of study	Day	Date	Break times	Ambient EUV dose (MED units)
1	Monday	26 February 2001	10:00 – 10:30	1.88
			10:30 – 11:00	2.34
			(10:00 – 11:00)	4.31
			11:00 – 12:00	5.47
2	Tuesday	27 February 2001	10:00 – 10:30	1.71
			10:30 – 11:00	2.16
			(10:00 – 11:00)	3.87
			11:00 – 12:00	2.71
3	Wednesday	28 February 2001	10:00 – 10:30	0.69
			10:30 – 11:00	1.65
			(10:00 – 11:00)	2.35
			11:00 – 12:00	3.41
4	Thursday	1 March 2001	10:00 – 10:30	1.99
			10:30 – 11:00	2.32
			(10:00 – 11:00)	4.30
			11:00 – 12:00	5.29
5	Friday	2 March 2001	10:00 – 10:30	0.89
			10:30 – 11:00	2.24
			(10:00 – 11:00)	3.13
			11:00 – 12:00	5.30
6	Saturday	3 March 2001	10:00 – 10:30	1.23
			10:30 – 11:00	2.20
			(10:00 – 11:00)	3.43
			11:00 – 12:00	5.21
7	Sunday	4 March 2001	10:00 – 10:30	1.67
			10:30 – 11:00	2.28
			(10:00 – 11:00)	3.96
			11:00 – 12:00	5.01

Table 4.16 indicates the amount of time spent outdoors as a function of gender. For all age groups, both male and female subjects spent more time outdoors on weekend days, with male subjects of the two younger age groups showing the largest differences between weekdays and weekend days. Considering the mean values in Table 4.18, the older age group spent relatively less time outdoors compared to the two other age groups, which may account for their relatively lower daily PSFB doses.

Table 4.15: The mean, median and 95% range of time spent outdoors in hours per day for each age group for days during a school term as calculated using the journal entries

(a)

Ages 4-6	Day of the week						
	1	2	3	4	5	6	7
Mean	1.83	2.03	2.22	1.99	1.74	2.73	2.17
Median	1.50	1.54	2.25	1.91	1.50	2.50	1.25
95% range	0.11-4.63	0.85-4.89	0.82-3.83	0.10-3.90	0.09-3.81	0.15-6.17	0.13-5.36

(b)

Ages 7 - 9	Day of the week						
	1	2	3	4	5	6	7
Mean	2.33	2.65	2.70	2.69	2.59	2.84	2.74
Median	2.50	2.37	2.25	2.58	2.50	2.83	2.12
95% range	0.10-4.06	0.94-5.05	1.06-6.84	0.53-4.96	1.01-4.73	0.15-5.85	0.22-8.77

(c)

Ages 13-14	Day of the week						
	1	2	3	4	5	6	7
Mean	2.72	2.09	2.29	2.38	1.46	2.18	2.44
Median	2.75	1.45	2.41	2.33	1.29	1.91	1.91
95% range	1.08-4.41	0.69-5.05	0.74-3.59	0.70-5.13	0.10-3.90	0.11-4.38	0.15-6.09

Table 4.16: The mean and median of time spent outdoors in hours per day for each age group as a function of gender

Age group		Male		Female	
		Weekday	Weekend	Weekday	Weekend
4 – 6 years	Mean	2.23	4.06	2.02	2.13
	Median	2.25	4.25	2.00	2.50
7 – 9 years	Mean	2.76	3.81	2.54	3.08
	Median	2.83	3.50	2.33	2.25
13 – 14 years	Mean	2.65	2.67	1.84	2.78
	Median	2.83	1.83	2.17	2.33
All subjects	Mean	2.54	3.52	2.14	2.75
	Median	2.66	3.25	2.16	2.25

Whilst the amount of time spent outdoors is clearly of paramount importance in determining individual EUV dose, the influence of shading is also significant. Environmental shading constitutes two types: shade from trees and shade from artificial constructions including buildings, shade cloth and coloured fibreglass roofing. Shade provided by anatomic sites of the subject's body is not considered here. Sun protective strategies usually emphasise the importance of using shade as a means of reducing individual ultraviolet radiation exposure. Many people select shaded areas when outdoors for thermal comfort preferences. However, research has shown that not all types of shading are effective ultraviolet radiation protective strategies in reducing ultraviolet radiation exposure. (Parisi *et al.*, 2000b).

Parisi and Kimlin (1999) found that ultraviolet radiation reduction in tree shade was dependent on the foliage density of the canopy, height of the sides of the tree from the ground, tree height and leaf flicker. Ultraviolet radiation protection increased with increased foliage density, while the presence of leaf flicker creates great variability in the level of ultraviolet radiation protection afforded by tree shade (Parisi and Kimlin, 1999). Diffuse ultraviolet radiation has also been observed at greater intensities in tree shade as a result of Rayleigh scattering and scattering by leaves in the tree canopy (Parisi *et al.*, 2000b). Diffuse ultraviolet radiation tends to consist of the shorter UVB wavelengths that are known to be highly effective in inducing adverse health effects on human skin (Parisi and Kimlin, 1999; Parisi *et al.*, 2000b). The relative position of individual trees is also important in affecting the level of ultraviolet radiation protection afforded by tree shade (Grant *et al.*, 2000). Maximum ultraviolet radiation protection occurs when individuals are located in full shade conditions and negligible sky is visible from that location (Grant *et al.*, 2000).

The results of this study indicate that 15.2% of the total 210 subject-days (30 subjects and 7 days) were days when subjects spent all of their indicated time intervals outdoors in the sun. A total of 35.9% were days when subjects spent all of their ultraviolet radiation exposure intervals in shade and 48.9% were days when subjects spent some of their indicated exposure periods in the sun and others in the shade. Evidently there is some recognition by children and adolescents of the role that shade may play in reducing an individual's EUV dose. Moreover, this may explain the relatively low daily PSFB doses of all the subjects during the study period. Subjects

may have purposefully found shaded areas while outdoors or unintentionally been in areas where trees or human structures obstructed the direct solar beam.

A more detailed analysis of the relationship between human ultraviolet radiation exposure and shade conditions is required in order to implement more efficient ultraviolet radiation protective strategies. The results of this study do not allow for a detailed analysis of the impact of shade on the subjects' PSFB doses since the badges provide a cumulative daily EUV dose rather than a time-dependent dose. Quantitative measurements of this nature are needed in order to analyse further the effect of shade and to develop and assess ultraviolet radiation protection strategies.

4.8.2 Ultraviolet radiation dose as a function of day of the week

Application of a non-parametric analysis of variance showed that, at a 95% confidence level, there was a statistically significant difference between the weekday and weekend PSFB doses of the 7 – 9 year and 13 – 14 year age groups. However, there was no significant difference for that of the 4 – 6 year age group. Table 4.17 shows that the mean and median PSFB doses for both the 7 - 9 year old subjects and the 13 - 14 year old subjects is greater on weekend days. This may be the result of a change in outdoor activities between weekdays and the weekend since these subjects may have more time available to them on weekend days. The younger age group shows almost no variation between weekdays and weekend days as a result of more consistent ultraviolet radiation exposure durations for all days of the week.

Table 4.17: The mean and median weekday and weekend daily PSFB doses (MED units) with respect to age

Age group	Weekday		Weekend	
	Mean	Median	Mean	Median
4 – 6 years	1.11	0.58	1.01	0.57
7 – 9 years	0.73	0.65	1.95	1.08
13 – 14 years	0.76	0.47	1.62	0.62

A study conducted in the Northern Hemisphere by Diffey *et al.* (1996) measured the weekday and weekend EUV doses of young children, living in 3 districts of England and aged between 9 - 10 years and 14 - 15 years of age (Table 4.18). Each subject wore one PSFB for Monday to Friday and a second badge for Saturday and Sunday.

Table 4.18: The weekday (Monday – Friday) and weekend (Saturday and Sunday) median PSFB dose (MED units) with respect to age and geographical area (adapted from Diffey *et al.*, 1996)

	Weekday		Weekend	
	Ages 9-10	**Ages 14-15**	**Ages 9-10**	**Ages 14-15**
Durham	2.3	1.4	0.6	0.2
Wallingford	2.3	1.5	1.1	0.6
Plymouth	2.3	1.0	1.1	0.4

It is interesting to note that, when comparing the daily PSFB doses for subjects aged 7 - 9 years and 13 - 14 years measured in this particular study with those observed by Diffey *et al.* (1996), the cumulative doses for five days of ultraviolet radiation exposure in England was only three times greater than the dose received for one weekday by a South African individual. Moreover, the PSFB doses received by the English children for both Saturday and Sunday together were less than that received on one weekend day by a South African child of a similar age. This may be on account of higher ambient EUV monitored in South Africa due to its geographical latitude and climatic conditions or due to longer ultraviolet radiation exposure periods undertaken by South African children due to favourable weather conditions encouraging an outdoor lifestyle.

Gies *et al.* (1998) measured the ultraviolet radiation doses of primary school children (aged 12 years) over a two-week period during summer in Brisbane, Australia. Each child wore one PSFB per day attached to the top of the shoulder. The variation between the PSFB doses for weekdays and weekend days of the study are compared with the oldest age group (13 - 14 years) of this particular study in Table 4.19.

The weekday median PSFB dose for males and females in Brisbane is greater than for both genders in Durban. This may be on account of the PSFB that was attached to the shoulder which is a more horizontal anatomic site compared to the lapel anatomic site. The Brisbane children's weekend PSFB doses are less than their weekday PSFB doses. This is in direct contrast to the Durban subjects whose weekend PSFB doses are greater than their weekday PSFB doses. These trends are likely due to different exposure patterns and outdoor activities undertaken by the two groups of children.

Table 4.19: The median weekday and weekend PSFB doses (MED units) for children in Brisbane compared with children in Durban (Adapted from Gies *et al.*, 1998)

	Weekday		Weekend	
	Brisbane males	**Durban males**	**Brisbane males**	**Durban males**
Median	2.30	0.83	0.33	1.26
	Brisbane females	**Durban females**	**Brisbane females**	**Durban females**
Median	1.00	0.38	0.37	0.44

4.8.3 Application of a general linear model

A general linear model, as described in SAS/STAT User's Guide (1990), was fitted to the logarithms of the subjects' PSFB doses with main effects for gender, age, skin type and day of the week. The logarithms of the PSFB doses were used since the PSFB doses did not fit a normal distribution and showed great variability within the data set. Only second order interactions and the interaction between day, gender and age were included in the model, since other higher order interactions were insignificant. The results of this analysis are included in Appendix VI.

The main effect for gender is significant with a p value = 0.0047 while the interaction between gender and age is also significant with a p value = 0.0033. The statistically significant relationship between PSFB dose and gender was also confirmed with the application of the Wilcoxon 2-sample test as stated in Section 4.7.2. The results of this model confirm that male subjects tended to receive higher PSFB doses than those of the female subjects. It was also interesting to note that the standard deviation of the

logarithms of the male subjects' PSFB doses was 0.93 while that of the female subjects' was 1.15. This suggests that there was greater variability amongst the female subjects' PSFB doses compared with the males.

The interaction between PSFB dose, gender and age was also identified as significant such that the logarithms of the mean PSFB doses for females tended to be greater for the 7 – 9 year old age group, while that of the males was greater for the 4 – 6 and 13 – 14 year old age groups (Appendix VI). This reinforces the significant difference between male and female PSFB doses mentioned above and adds an additional component, age, to that difference.

4.8.4 Role of activities

Human exposure to ultraviolet radiation is dependent on a number of factors including behaviour and activities. Due to the variability of human behaviour, this factor is possibly the least explored, particularly amongst children and adolescents. In an attempt to determine which factor provides the most explanatory power in terms of individual ultraviolet radiation exposure, the subjects' activities and behaviour patterns were examined. It was found that the nature of the subjects' highly variable behaviour was the reason for the variability amongst the daily PSFB doses.

The differences in the subjects' PSFB doses cannot be accounted for entirely by differences in time spent outdoors as these were relatively similar for each age group. They are therefore a reflection of differences in behaviour patterns, the nature of activities undertaken and associated human movement. In the analysis of the role that these factors played in the PSFB dose, it was assumed that the provision of PSFB to the subjects did not introduce a Hawthorne effect. This is defined as a condition when a participant's normal behaviour is influenced by their involvement in a study (www.inverson software.com/sociology/hawthorne_effect.htm).

Typical behaviour patterns during school term were identified as being associated with the daily school structure, namely, the beginning of the school day at approximately 7:30, a tea break between approximately 10:00 and 10:30 and lunch between approximately 12:00 and 13:00, with some variability between each age

group. There was a large range of activities undertaken by the subjects after school hours namely after 12:00, 13:15 and 14:30 for the three respective age groups. These included outdoor extramural and recreational activities such as swimming (at the pool and the beach), cricket, golf, cycling, tennis, karate, observing sport events, sun tanning, ball skills and playing (in the playground and the garden).

Since the subjects' PSFBs measured their total daily EUV dose it was not possible to determine the amount of ultraviolet radiation received during particular activities. However, contributing to the complexity of analysing the relationship between the PSFB doses and varying activities, is the orientation of the anatomic site (lapel site) towards the direct solar beam. Holman *et al.* (1983) calculated the amount of EUV received on the cheek and hand as a percentage of the ambient EUV during five different activities (Table 4.20).

Table 4.20: Mean proportion of ambient EUV (%) received at 2 anatomic sites on living subjects engaged in 5 activities (Adapted from: Holman *et al.*, 1983)

Outdoor activity	Cheek	Hand
Suntanning	35	48
Golf	24	51
Tennis	26	32
Swimming (pool)	26	57
Cricket	18	32

Certain outdoor activities result in higher EUV doses than other activities and in different proportions on various anatomic sites. Swimming, suntanning and golf all received relatively high percentages of the ambient EUV compared to tennis and cricket. In order to gain some understanding of the activities undertaken by the subjects in this study in relation to their daily PSFB doses, the ten highest PSFB doses, for all days and all subjects, were identified and are presented in Table 4.21.

All of the highest daily PSFB doses were greater than 3 MED units and therefore constituted some risk of erythema depending on the skin type of the subject. Five of the ten highest PSFB doses were for subjects between 13 - 14 years of age. Although

the average and median PSFB dose for this age group was relatively lower than the other two age groups, there were still subjects who received high PSFB doses. The majority of the highest PSFB doses were measured on weekend days (70%), when subjects had more spare time available for outdoor leisure pursuits.

Table 4.21: The ten highest daily PSFB doses (MED units) from all of the age groups

Subject number	Skin type	Age	Day of the week	PSFB dose (MED units)	Activity	Clothing worn during activity	Exposure duration between 10:00 - 15:00 (minutes)
18	V	8	Sun	7.40	Swimming	Swimming trunks	90
14	III	8	Sun	6.44	Swimming	Swimming costume	90
5	V	6	Wed	6.19	Swimming	Swimming costume	135
22	III	13	Sun	5.08	At the beach	Bikini	195
15	III	8	Sat	5.04	At the beach	Bikini	100
30	V	14	Sat	4.73	Cricket	T-shirt	185
30	V	14	Sun	4.29	Golf	T-shirt	150
3	III	5	Wed	3.94	Swimming	Swimming costume	135
26	II	14	Sun	3.90	Cycling	T-shirt	75
26	II	14	Mon	3.76	Watching a gala	Short-sleeve school shirt	80

Swimming was one of the most frequently pursued activities, possibly due to the study having been conducted during late summer when air temperatures and humidity levels were high. Although other studies have confirmed this (Holman *et al.*, 1983), the magnitude of the PSFB dose may have been influenced by the fact that the subjects were told to remove the non-waterproof PSFB during swimming periods and place it on a dry, horizontal surface in close proximity to where they were swimming. It is likely that the orientation of the PSFB was of a horizontal nature and consequently received an EUV dose similar to the ambient EUV levels until the PSFB

was re-attached to the lapel site. As indicated in Table 4.21 all the exposure durations for the days with the ten highest PSFB doses were longer than 1 hour, with two extending up to 3 hours. The highest PSFB dose did not correspond with the longest exposure duration between 10:00 - 15:00, thereby highlighting the complexity of the factors influencing human ultraviolet radiation exposure, namely duration of exposure and time of day.

Figure 4.18 shows the subjects' PSFB dose for each day of the week for each age group. The highest PSFB dose for each day has been annotated with the activity conducted by that particular subject that most likely contributed towards their PSFB dose. The majority of the PSFB doses lie below 200 J m^{-2}. Those PSFB doses lying above 200 J m^{-2} indicate the influence that outdoor activities such as swimming, playing in the garden and sports have on increasing the daily PSFB dose of a subject. This highlights the difficulty of understanding additional factors such as the nature of the activity, timing and duration of exposure, orientation of the anatomic site and degree of shading. The extent and severity of ultraviolet radiation damage experienced by each subject seems to therefore be most dependent on the nature of the activity and associated behaviour, irrespective of age or gender.

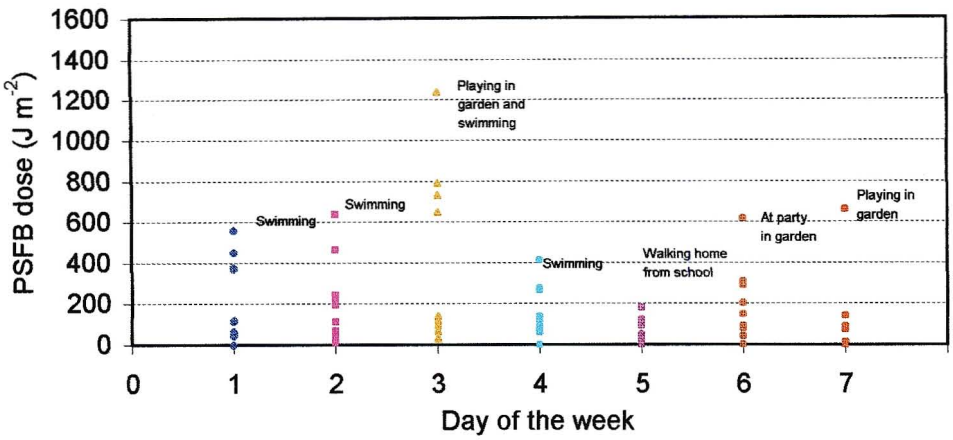
4.9 Application of an activity model

The nature of an activity and its associated behaviour has been identified as an important factor influencing individual ultraviolet radiation dose and is worthy of further detailed investigation. In order to do this, an activity model was derived using empirically based activity factors. This model is described below and the fieldwork used to determine the activity factors for three activities is provided.

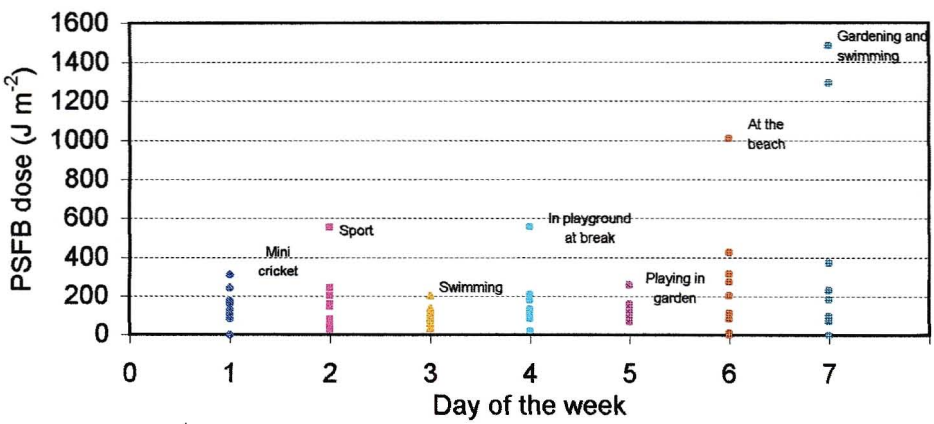
4.9.1 Derivation of activity factors

Individual EUV dose is dependent upon various factors where the nature of an outdoor activity or leisure pursuit is an important factor. Through the application of daily ambient EUV levels and knowledge of the timing and duration of each outdoor activity conducted on any particular day, an individual's daily EUV dose may be calculated as follows:

(a) Ages 4 - 6 years



(b) Ages 7 - 9 years



(c) Ages 13 - 14 years

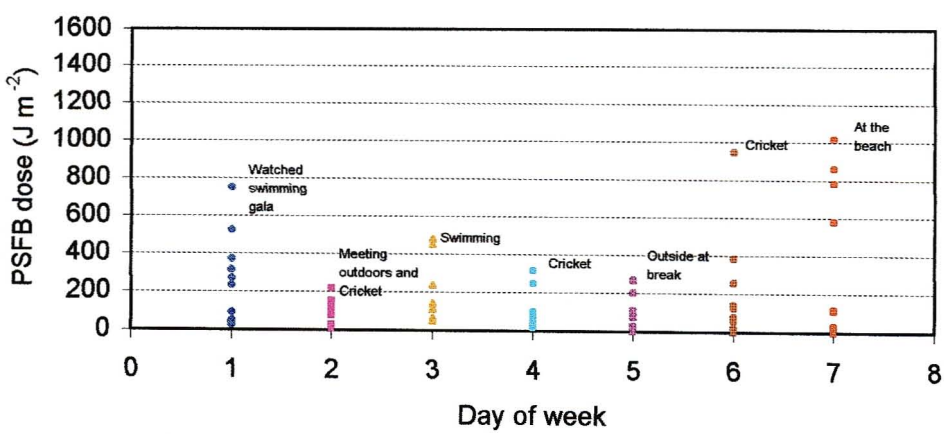


Figure 4.18: Subjects' PSFB doses for each day and activity of highest PSFB dose for that day

$$\text{Total daily EUV dose} = \sum_{n}(AEUV \times t \times AF) \qquad (4.1)$$

where n is each activity on one particular day, AEUV is the ambient EUV (W m^{-2}), t is the duration of the activity (seconds) and AF is the activity factor for that particular activity. The activity factor is an important component of this model and is investigated further in this study.

Ambient EUV levels at the time of the activity may be determined using actual daily values measured by a UVB-1 pyranometer, forecast ultraviolet radiation values or calculated using a radiative transfer model. A radiative transfer model was used by Bodeker (pers. comm., 2001), in a similar manner to McKenzie and Elwood (1990), to estimate the average seasonal and diurnal variations in EUV for one year for Durban using total column ozone measurements for 1996 - 2000 (Figure 4.19). This radiative transfer model allows for the calculation of ambient EUV levels at any particular latitude and longitude (McKenzie and Elwood, 1990). In this manner, it is possible to predict ambient EUV as a function of time of the day and day of the year for Durban.

The activity factors may be extrapolated from past empirical studies, e.g. conducted by Holman *et al.* (1983) and Herlihy *et al.* (1994). These factors are available for certain anatomic sites including the cheek, hand, shoulder, back, chest, thigh, calf and thoracic spine (Table 4.22). It is believed that activity factors have not been calculated for the South African context and thus a preliminary study was undertaken.

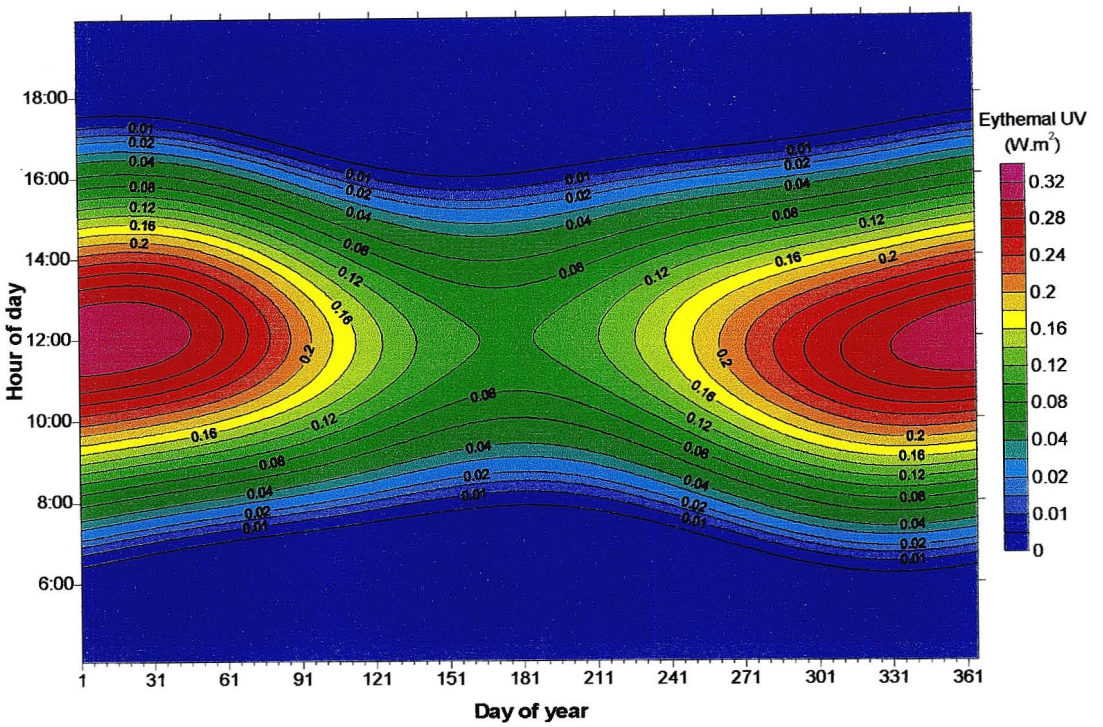


Figure 4.19: Model calculation of ambient EUV for Durban (McKenzie and Elwood, 1990; Bodeker, pers. comm., 2001)

Table 4.22: Activity factors for 11 outdoor activities for the hand anatomic site (After: Holman *et al.* (1983) and Herlihy *et al.* (1994))

Activity	Activity Factor	Activity	Activity Factor
Boating	0.60 ± 0.21	**Sailing**	0.49 ± 0.25
Cricket	0.32 ± 0.04	**Sunbathing**	0.48 ± 0.20
Fishing	0.48 ± 0.11	**Swimming**	0.59 ± 0.36
Gardening	0.15 ± 0.09	**Tennis**	0.40 ± 0.21
Golf	0.26 ± 0.12	**Walking**	0.24 ± 0.06
Hiking	0.46 ± 0.02		

The aim was to compare the empirically derived activity factors in Table 4.22 with those calculated in this study. Two objectives were identified as:

- To determine whether the activity factors presented in Table 4.22 were appropriate for use in the South African context.
- To determine whether the activity factors remained constant throughout the day.

In order to fulfil these objectives, three volunteers were recruited. Each volunteer signed a consent form (Appendix II) and Ethics Approval was granted by the Ethics Committee based at the Nelson Mandela Medical School, University of Natal (Durban). The study took place on 18 November 2001 (Day 322), a clear sky day with a maximum temperature of 30°C. Each volunteer wore one waterproof PSFB attached to the right hand per hour, for 8 continuous hours and performed one of 3 activities, namely, swimming, walking, sunbathing and tennis, as indicated in Table 4.23. Ambient EUV, recorded by a YES UVB-1 pyranometer that was located approximately 8 km from the point where the activities were conducted, is presented in Figure 4.20. Cloud was not considered, however, a cloud factor may be incorporated into the activity model.

Table 4.23: Rotation of the activities amongst the volunteers

Time	Volunteer 1	Volunteer 2	Volunteer 3
8:00-9:00	Swim	Walk	Tennis
9:00-10:00	Walk	Tennis	Swim
10:00-11:00	Tennis	Swim	Walk
11:00-12:00	Swim	Walk	Tennis
12:00-13:00	Walk	Tennis	Swim
14:00-15:00	Tennis	Swim	Walk
15:00-16:00	Swim	Walk	Tennis

Pre- and post-exposure absorbance measurements of the PSFBs were done using a Varian DMS 300 UV-Visible spectrophotometer, the ΔA_{330} for each PSFB was calculated and the EUV dose (J m^{-2}) was determined from the calibration equation in Section 3.4. The ambient EUV dose for each hourly interval was calculated using the YES UVB-1 pyranometer EUV measurements. It should be noted that the volunteers had lunch indoors between 12:00 - 12:15 and therefore the calculated ambient EUV dose during 12:15 - 13:00 was less than the actual EUV dose of 1266.19 J m^{-2} measured between 12:00 - 13:00 on account of the time spent indoors by the volunteers. These data are presented in Table 4.24 and Figure 4.21.

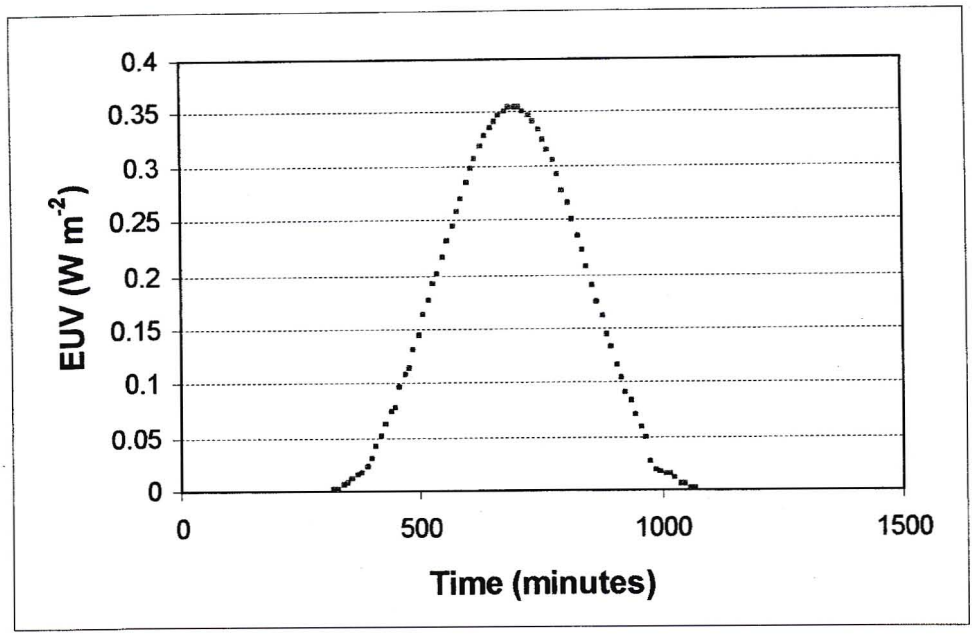


Figure 4.20: Ambient EUV (W m^{-2}) for 18 November 2001 (Day 322)

Table 4.24: Hourly PSFB doses in EUV (J m^{-2}) for each activity and hourly ambient EUV dose (J m^{-2})

Hour period	Walking	Tennis	Swimming	Ambient EUV
8:00 – 9:00	125.16	252.90	252.90	319.00
9:00 – 10:00	274.19	255.23	416.25	604.75
10:00 – 11:00	296.31	367.58	562.63	902.14
11:00 – 12:00	319.25	407.44	703.53	1157.03
12:00 – 13:00	311.51	362.05	509.28	1162.38
13:00 – 14:00	319.25	345.69	367.58	1180.09
14:00 – 15:00	227.99	274.19	319.25	924.76
15:00 – 16:00	145.96	166.29	259.91	603.71
Average	252.44	303.96	423.92	856.73

Swimming consistently received the highest PSFB dose for all hourly intervals during the day, followed by tennis and then walking. The hourly PSFB dose of each activity as a ratio of the ambient EUV dose, in other words the activity factor, for that hour did not remain constant throughout the day (Table 4.25). Figure 4.22 indicates that these ratios tended to decrease over the course of the day from 0.39, 0.79 and 0.79, to 0.24, to 0.28 and 0.43 for walking, tennis and swimming respectively. This suggests

that it may not be possible to use the same activity factor for one particular activity conducted at different times during the day.

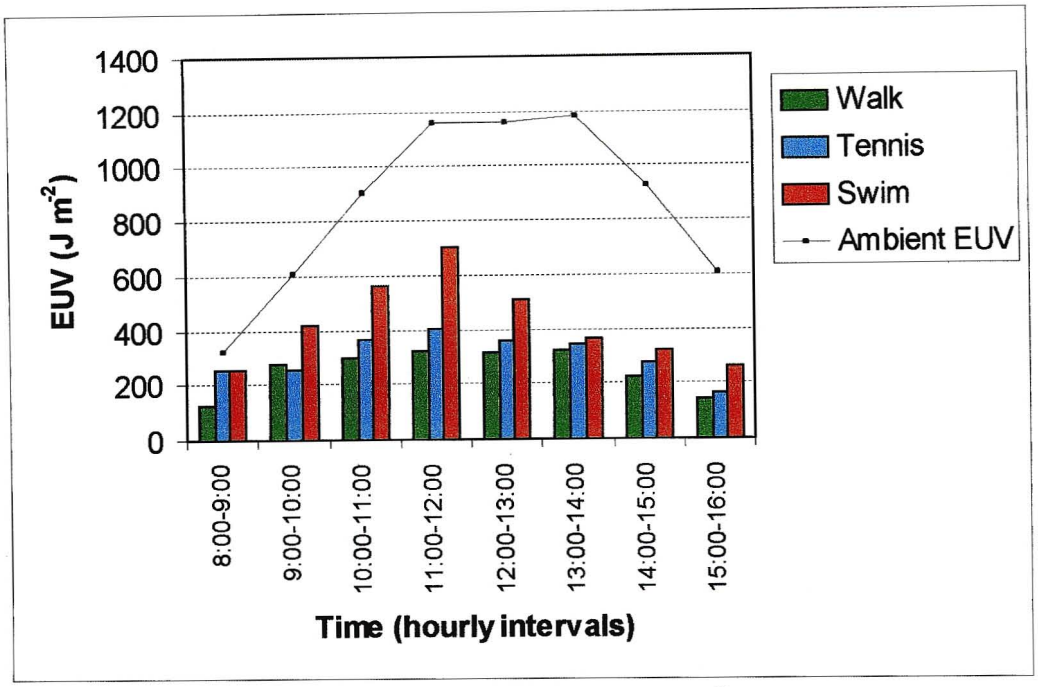


Figure 4.21: Comparison between the PSFB doses (J m^{-2}) for the three activities and the hourly ambient EUV doses for 18 November 2001

Table 4.25: PSFB doses for each activity for each hour as a ratio of the ambient EUV dose for that hour

Hour period	Walking	Tennis	Swimming
8:00 – 9:00	0.39	0.79	0.79
9:00 – 10:00	0.45	0.42	0.69
10:00 – 11:00	0.33	0.41	0.62
11:00 – 12:00	0.28	0.35	0.61
12:00 – 13:00	0.27	0.31	0.44
13:00 – 14:00	0.27	0.29	0.31
14:00 – 15:00	0.25	0.30	0.35
15:00 – 16:00	0.24	0.28	0.43
Average for this study	0.31	0.39	0.53
Activity factors from Table 4.24	0.24	0.40	0.59

A comparison with the activity factors provided in Table 4.22 extracted from previous international studies, i.e. Holman *et al.* (1983) and Herlihy *et al.* (1994), and the

activity factors for this study are similar for tennis and swimming. This is not the case for walking, however, which may be due to the influence of tree shade as an individual may sporadically walk under a tree during this activity.

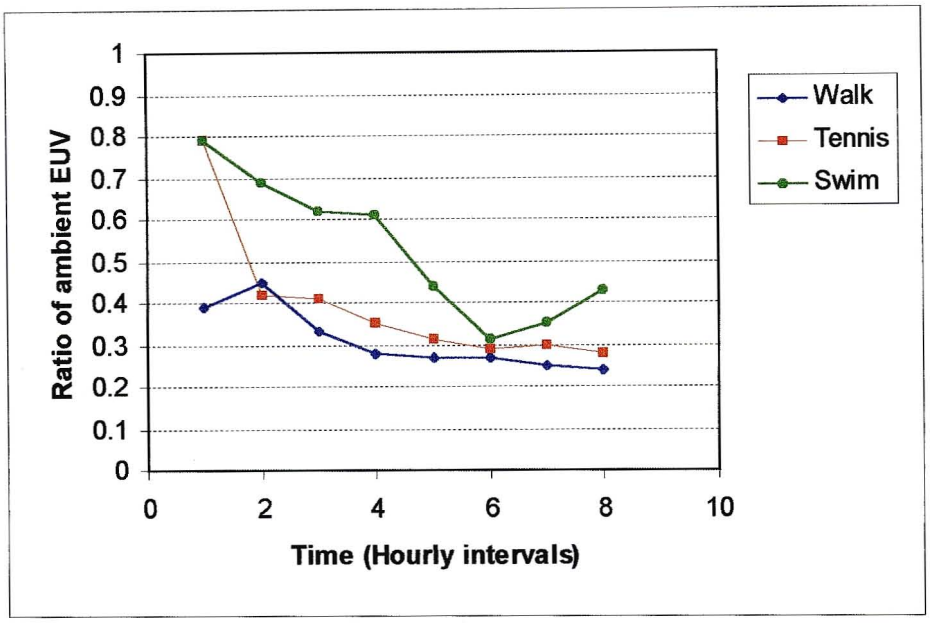


Figure 4.22: PSFB dose of each activity as a ratio of the ambient EUV dose

The appropriateness of the activity factors was therefore assessed in terms of their validity in the South African context and found to be similar to those derived in other international studies. A comparison was made in order to test whether they remain constant throughout the day and it was found that this is not the case. Therefore, it would appear that the activity factors component of the activity model requires further investigation, however, the model itself may be of great value in the prediction of individual EUV doses for a particular activity based on timing and duration. The ability to determine such information may play an important role in the school system, particularly in the scheduling of outdoor sports event such as swimming galas and athletics meetings. Evidently, this innovative model has the potential to be used as a means of forecasting an individual's EUV dose and may serve to illustrate the need for responsible outdoor behaviour with regard to ultraviolet radiation exposure.

Chapter Five

THE ANATOMICAL DISTRIBUTION OF ULTRAVIOLET RADIATION

5.1 Introduction

This chapter provides an analysis of the anatomical distribution of ultraviolet radiation. A description and interpretation of the anatomic erythemal ultraviolet radiation (EUV) doses quantified through the application of PSF strips attached to a mannequin under clear and cloudy skies is presented. A discussion of the raw data acquisition and methodology was included in Section 3.11. The results of this work are related to the PSFB doses of the children and adolescents in Durban and recommendations concerning the health implications of human exposure to ultraviolet radiation are made.

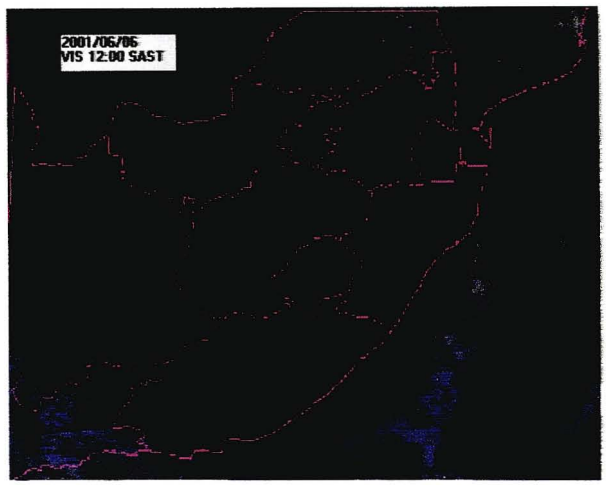
5.2 Anatomical distribution of erythemal ultraviolet radiation under clear sky conditions

The human body has a complicated topography, while the range of human movement, positions and orientations are both intricate and numerous. Holman *et al.* (1983) compared the anatomic EUV doses measured using mannequins with those measured using human beings. They found that the EUV doses of the mannequins were similar to those of humans. However, these may vary according to the posture and positioning of the mannequin. The systematic and staggered rotation of the mannequin is also not an ideal means of simulating natural human movement and thus mannequin studies may either overestimate or underestimate certain anatomic sites.

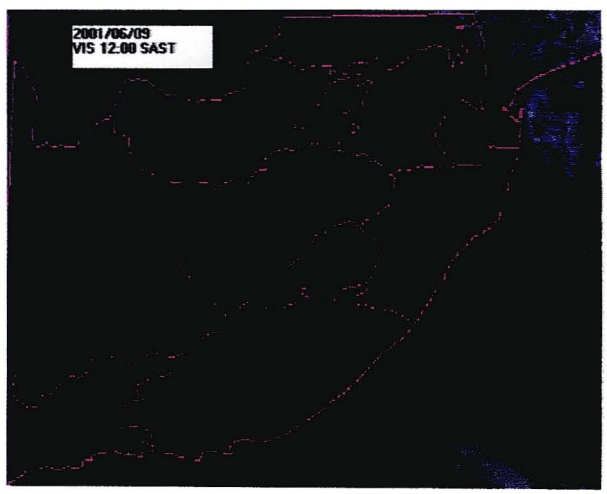
In this study, the relative distribution of ultraviolet radiation was measured at 26 anatomic sites on the surface of an upright, unclothed mannequin for two hours around local noon (12:00) on five clear sky days in June in Durban. Details pertaining to the method used are presented in Section 3.11. Plate 5.1 illustrates these clear sky conditions typical of winter in Durban and Figure 5.1 shows the ambient EUV for the four of the five days of the study using data from the YES UVB-1 pyranometer. The

mean EUV dose (J m^{-2}) for each of the 26 anatomic sites outlined in Figure 3.5 is presented in Table 5.1.

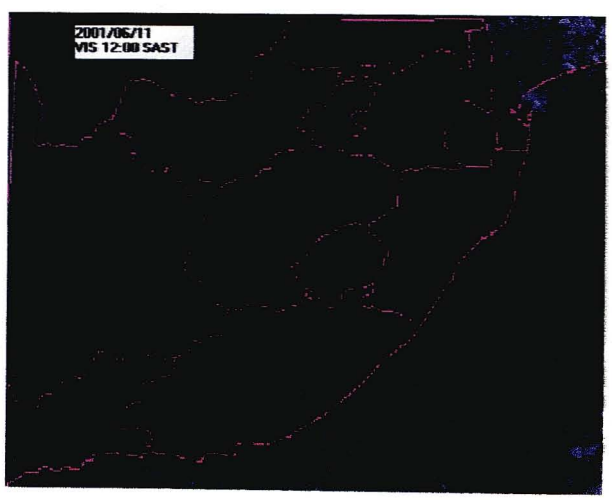
(a)



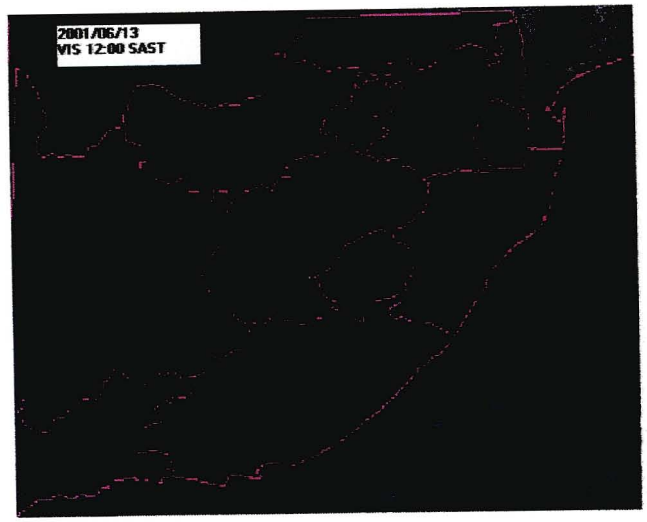
(b)



(c)



(d)



(e)

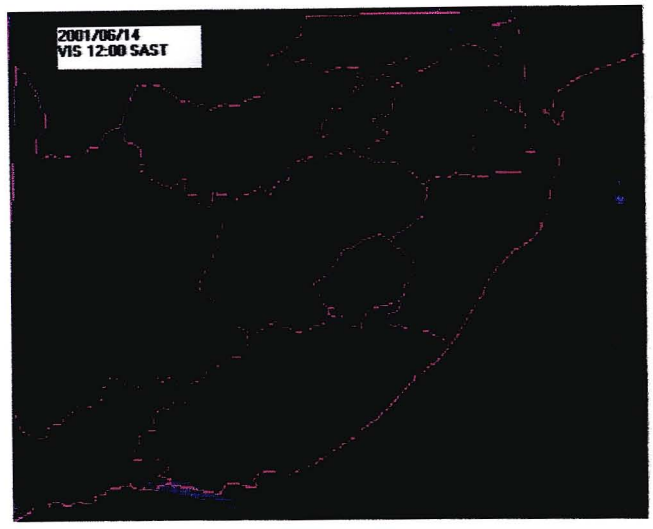
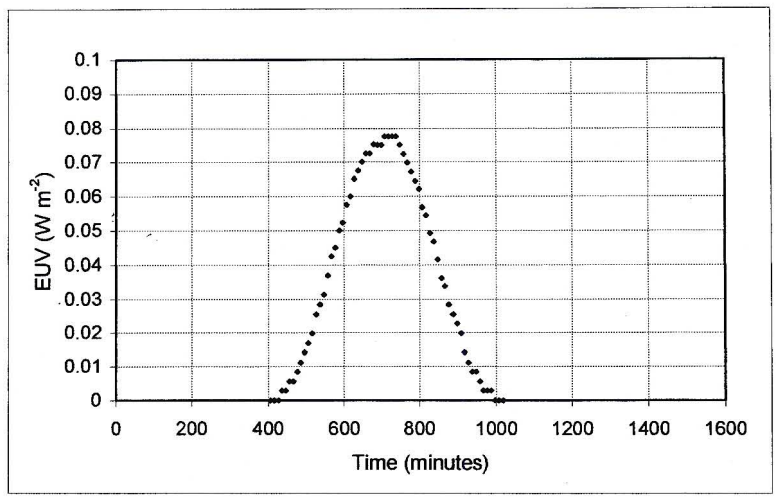


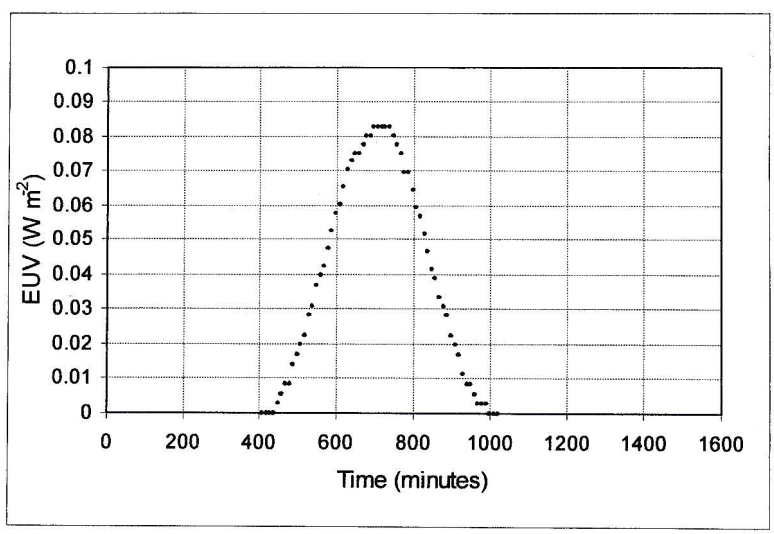
Plate 5.1: Meteosats showing clear sky conditions over Durban for (a) 6 June 2001, (b) 9 June 2001, (c) 11 June 2001, (d) 13 June 2001 and (e) 14 June 2001 (Courtesy of: SAWS, 2001)

The mean EUV doses ranged between 36.12 - 272.72 J m^{-2}. The EUV doses measured between 11:00 - 12:00 were similar to those measured between 12:30 - 13:30, except for the anatomic sites on the sides of the body, i.e. side of left ear, left cheek and front of right hand, due to the changing position of the sun and the effect of rotating the mannequin (Table 5.1; Plate 5.2). The highest mean EUV dose of 272.72 Jm^{-2} was received on the vertex of the head as expected since the vertex is the most horizontal anatomic site and is never shaded by another anatomic site (Diffey *et al.*, 1977; 1979).

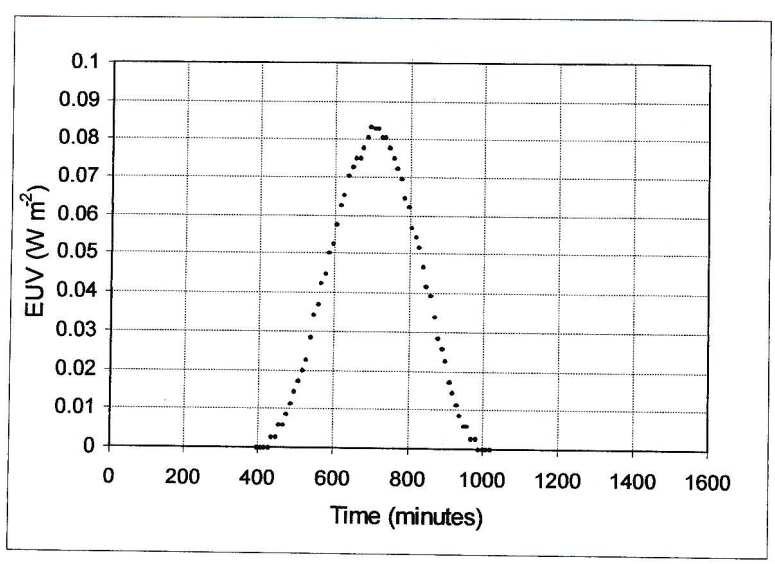
(a) 9 June 2001



(b) 11 June 2001



(c) 13 June 2001



(d) 14 June 2001

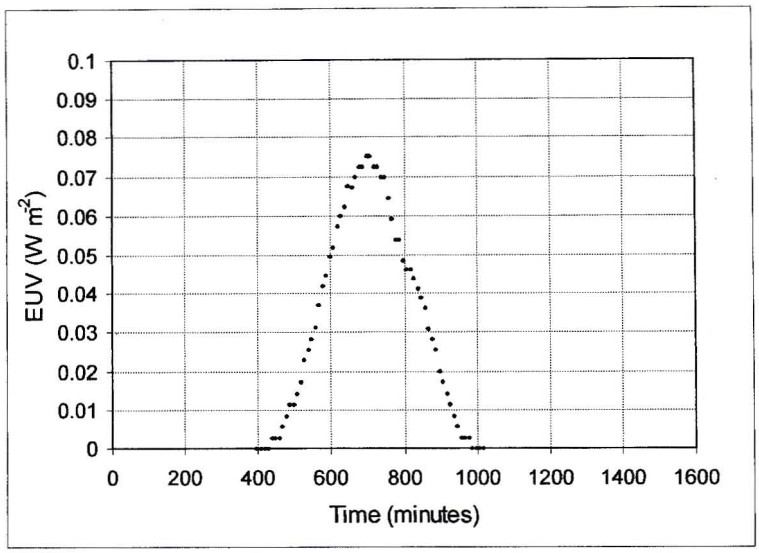


Figure 5.1: Ambient EUV (W m^{-2}) as recorded by the YES UVB-1 pyranometer in Durban for the four days of the study period using the mannequin

The vertex is often used as a benchmark against which the EUV doses of other sites are compared. All anatomic sites are normalised to the vertex, the site of the maximum EUV dose, to eliminate variations in absolute ultraviolet radiation intensity on a day-to-day basis. The shoulder and the chest received relatively high EUV doses of 222.58 J m^{-2} and 206.38 J m^{-2} respectively. The angle of the shoulder was horizontal and thus similar to the vertex, however the high EUV dose of the chest cannot be attributed to a horizontal orientation. The chest of the mannequin used in this study was slightly protruding at approximately 45°. This may have overestimated its EUV dose as a result of its angular plane and the relatively long neck and poised head of the mannequin that prevented any shading of this anatomic site.

The lower back received the lowest EUV dose of 36.12 J m^{-2}. This anatomic site is slightly concave which reduces the amount of EUV incident upon it (Plate 5.3). The hand received a relatively high EUV dose of 182.52 J m^{-2} on account of the mannequin's positioning and orientation of the hand rather than it lying directly alongside the trunk (Plate 5.4).

Table 5.1: Mean EUV doses (J m^{-2}) for the 26 anatomic sites on the mannequin measured on 5 clear sky days

Anatomic site	Morning (11:00-12:00) EUV dose (J m^{-2})	Afternoon (12:30-13:30) EUV dose (J m^{-2})	Mean EUV dose (J m^{-2})	Percentage of the vertex (%)	Percentage of the lapel (%)
Control	242.72	249.44	246.08		
Horizontal sites					
Vertex of the head	274.36	271.07	272.72	100.0	162.8
Top of left ear	111.15	148.32	129.73	47.6	110.23
Right shoulder	214.62	230.55	222.58	81.6	96.10
Vertical sites					
Forehead	141.23	165.37	153.30	56.2	121.86
Left cheek	100.19	68.46	84.32	30.8	86.70
Right temple	95.56	105.47	101.02	37.0	127.96
Side of left ear	59.55	44.63	52.09	19.0	61.50
Right scapular	72.92	80.27	76.59	28.0	56.84
Back of right upper arm	77.64	86.12	81.88	30.0	48.30
Back of right elbow	66.80	56.58	61.69	22.6	69.63
Nape of neck	72.61	76.23	74.42	27.2	54.64
Centre of upper back	99.14	94.38	96.76	35.4	77.18
Centre of lower back	31.30	34.93	36.12	13.2	32.72
Centre of chest	208.28	204.49	206.38	75.6	108.74
Right kneecap	113.59	101.35	107.47	39.4	101.62
Back of left knee	130.44	136.53	133.46	48.9	115.86
Front of right mid-calf	104.98	97.83	101.40	37.1	89.47
Back of left mid-calf	117.04	105.35	111.19	40.7	65.23
Back of left ankle	121.05	101.16	111.10	40.7	49.16
Front of right foot	129.77	124.49	127.13	46.6	99.55
Angular sites					
Bridge of nose	147.71	155.99	151.85	55.6	84.46
Chin	114.84	110.95	112.90	41.4	69.70
Left lapel	172.61	166.02	169.31	62.0	100.00
Front of right mid-forearm	187.05	185.90	186.48	68.3	68.92
Front of right upper arm	170.48	163.94	167.21	61.3	43.47
Front of right hand	203.73	161.31	182.52	66.8	74.02

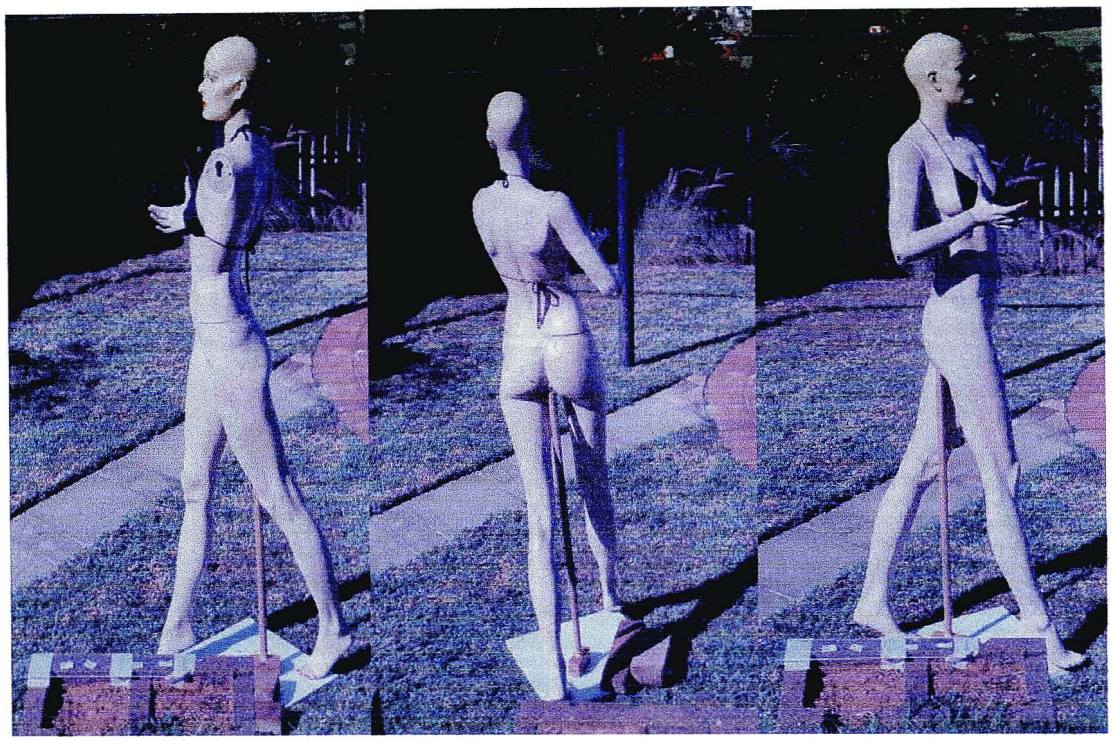


Plate 5.2: Rotation of the mannequin about true north (a) 45° to the right; (b) 90° to the right and (c) 120° to the right

According to Diffey (pers. comm., 2001), the EUV dose of the hands provides a good approximation to that of the facial area and the lapel site. In this instance, the EUV dose of the hand may have been overestimated due an exaggeration of its orientation towards the direct solar beam. Thus the EUV dose of the hand exceeded that of the facial area where different parts of the face received between 84.32 - 153.30 J m^{-2}. The lapel site received an EUV dose of 169.31 J m^{-2} that is only 13.21 J m^{-2} less than that of the hand.

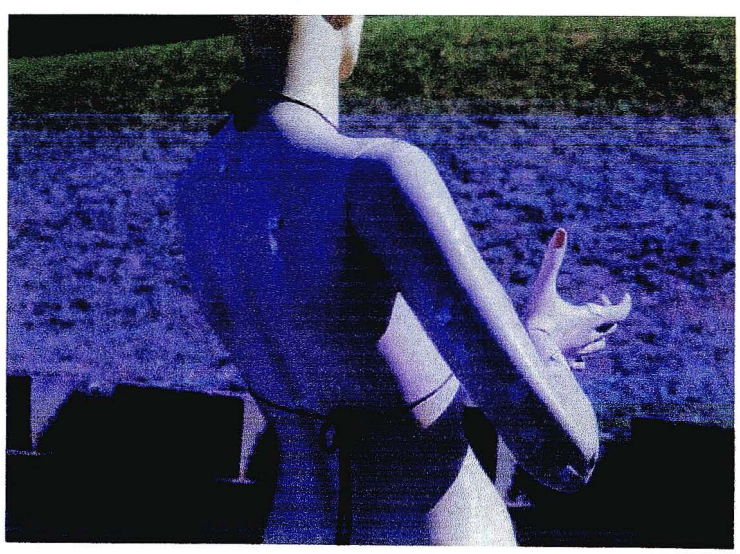


Plate 5.3: PSF strips attached to the neck, back and arm of the mannequin

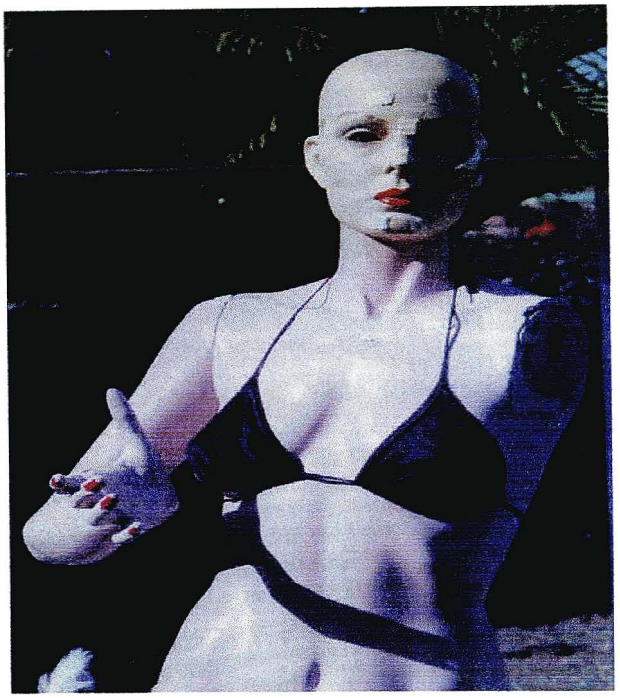


Plate 5.4: Positioning of the mannequin's arm to the body

The 26 anatomic mean EUV doses were converted into MED units, ranked and divided into categories (Table 5.2). These categories were used to graphically illustrate the anatomical distribution of ultraviolet radiation according to different bodily zones (Figure 5.2). The vertex and the shoulders were most susceptible to high EUV doses. The limbs received relatively high EUV doses yet the arms were more susceptible to ultraviolet radiation exposure compared to the legs due to shading (Plate 5.5).

The facial area, excluding the nose, chin, temple and top of the ears, received an EUV dose of between 50 - 100 J m^{-2} depending on the exact angular plane and orientation towards the direct solar beam of each anatomic site. The protruding parts of the face, i.e. nose, chin, forehead and top of the ears, were less protected and received relatively higher EUV doses than the remaining areas of the face. These sites were also more angular and less vertically oriented, resulting in a more intense EUV dose incident upon them.

Table 5.2: Division of anatomic sites into categories according to mean EUV doses (MED units)

Category	Mean EUV dose (MED units)	Anatomic sites
1	0 - 0.25	Lower back
2	0.255 - 0.5	Cheek, side of ear, scapular, back of upper arm, elbow, nape of neck, center of upper back
3	0.505 - 0.75	Chin, temple, top of ear, knee cap, back of knee, front of calf, back of calf, ankle
4	0.755 - 1.0	Forehead, nose, lapel, forearm, hand, front of upper arm.
5	1.005 - 1.25	Shoulder, chest
6	1.255 - 1.5	Vertex

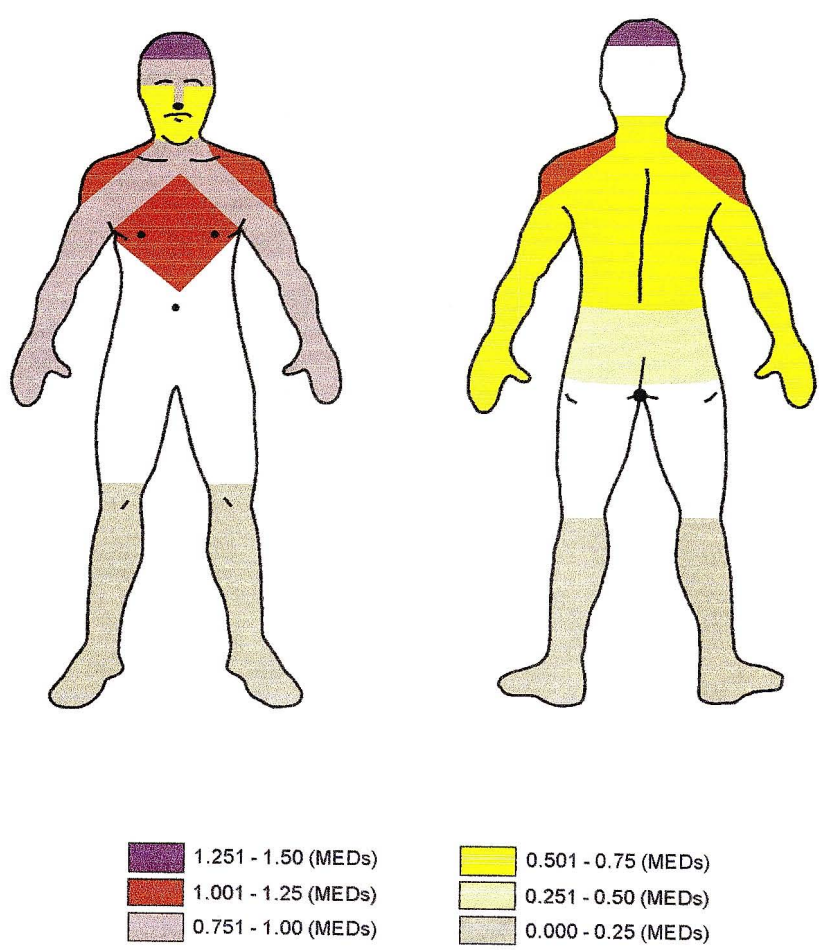


Figure 5.2: Anatomical distribution of EUV for the 26 anatomic sites forming six bodily zones

Table 5.1 also permits a comparison of the mean EUV doses as a function of the orientation of the anatomic site. The EUV doses of the horizontal surfaces were between 129.73 - 272.72 J m^{-2} and vertical surfaces received between 19.08 - 206.38 J m^{-2}. Horizontal surfaces tended to receive the highest EUV doses, followed by angular surfaces with vertical surfaces receiving the least. These findings are endorsed by the anatomical distribution of EUV shown in Figure 5.2.

(a) (b)

Plate 5.5: Shading of the (a) front and (b) back of the mannequin when facing true north.

Assuming the vertex to receive 100% of EUV, vertical surfaces tended to receive 50% or less, while horizontal surfaces with some shading received approximately 80% or less of the vertex. The dorsum of the foot is also typically a horizontally oriented surface, however, the foot of the mannequin used in this study was inclined towards the vertical plane and therefore received a reduced EUV dose (127.13 J m^{-2}) and a smaller percentage of 46.6% of the vertex amount. Table 5.3 compares the EUV doses of 6 anatomic sites relative to the vertex under clear sky conditions obtained by three different mannequin studies. The results of this study are in agreement with similar studies and serve to emphasise the differences in the amount of EUV received on different planes of the body of an upright person.

Holman *et al.* (1983) state that ultraviolet radiation dosimetry using mannequins may overestimate the EUV dose of the shoulder and chest and underestimate that of the lower back and upper arm. This arises from the stationary position of the mannequin compared with people who tend to move, stretch down and stoop forwards in a variety of movements thereby altering their ultraviolet radiation exposure orientation. Nevertheless, the results obtained using a mannequin indicate that certain parts of the human body are more susceptible to higher EUV doses than other sites and that their orientation towards the direct solar beam contributes towards the intensity of this EUV dose.

Table 5.3: EUV doses relative to the vertex at 6 anatomic sites for three different studies

Anatomic site	Diffey *et al.* (1977)	Diffey *et al.* (1979)	Kimlin *et al.* (1997)	This study (2001)
Vertex	100.0	100.0	100.0	100.0
Forehead	-	58.0	43.0	56.0
Nose	-	66.0	57.0	55.0
Chin	-	34.0	12.0	41.0
Cheek	31.0	29.0	21.0	30.0
Shoulder	68.0	-	80.0	81.0
Chest	73.0	-	-	75.0

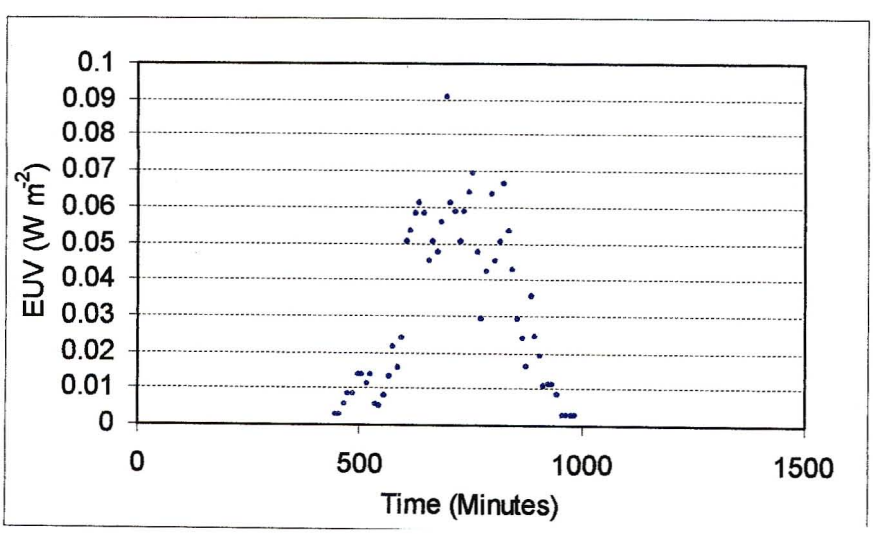
5.3 Anatomical distribution of erythemal ultraviolet radiation under overcast cloud conditions

The relationship between cloud cover and ultraviolet radiation is complex. Uniformly overcast skies are known to reduce surface ultraviolet radiation levels (Bodeker and McKenzie, 1996). Cloud parameters including cloud type, thickness, height and relative position to the solar disk affect the cloud's ability to suppress surface ultraviolet radiation. This study considered the anatomical distribution of EUV under overcast skies (7 - 8 octas) where the solar disk was permanently obscured and such that no clearing took place for four hours around local noon (Plate 5.6).

Plate 5.6: Typical overcast sky conditions on 15 August 2001

The relative distribution of EUV was measured using PSF at 26 anatomic sites on the surface of a mannequin for four hours around local noon on two overcast days, 15 August 2001 and 31 August 2001. Details regarding the method used are provided in Section 3.11. Ambient EUV conditions for the two days are presented in Figure 5.3. Figure 5.4 presents the average EUV doses (J m^{-2}) for each of the anatomic sites for the morning and afternoon. All of the anatomic EUV doses, except for the vertex of the head and the hand, lie below 200 J m^{-2} or 1 MED unit. Figure 5.5 compares the mean EUV doses for clear sky conditions (1 hour exposure) and overcast sky conditions (2 hour exposure) showing clearly the reduced nature of anatomic EUV doses under overcast sky conditions.

(a) 15 August 2001



(b) 31 August 2001

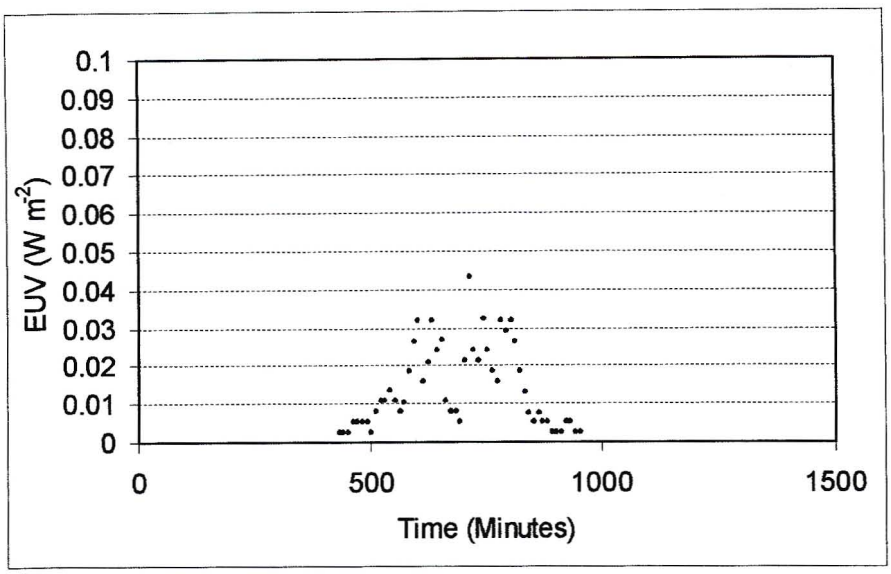


Figure 5.3: Ambient EUV (W m^{-2}) as recorded by the YES UVB-1 pyranometer in Durban for the two days of the study period

For overcast skies, the morning EUV doses were generally higher than the afternoon EUV doses. The vertex of the head, top of the ear, right shoulder, hand and chest received the highest EUV doses. These are horizontally oriented anatomic sites, excluding the hand and chest that received relatively high EUV doses on account of the positioning of the mannequin. Under overcast sky conditions, the anatomical distribution of EUV may be further complicated due to scattering and reflection by clouds, particularly on vertical and angular anatomic sites.

Individuals exposed to ultraviolet radiation on overcast days are likely to receive a lower EUV dose compared to clear sky conditions. Overcast days when the solar disk is not visible at any point during the day may therefore serve to protect individuals spending time outdoors in Durban from receiving consistently medium to high EUV doses.

Local climatic conditions therefore play an important role in influencing the amount of EUV received by an individual. In the instance of overcast skies, the EUV dose received by an individual tends to be reduced, however, the temporal and spatial variability of cloud makes it difficult to extrapolate these results for other cloud conditions, i.e. for partial cloud cover when the solar disk is obscured or partial cloud

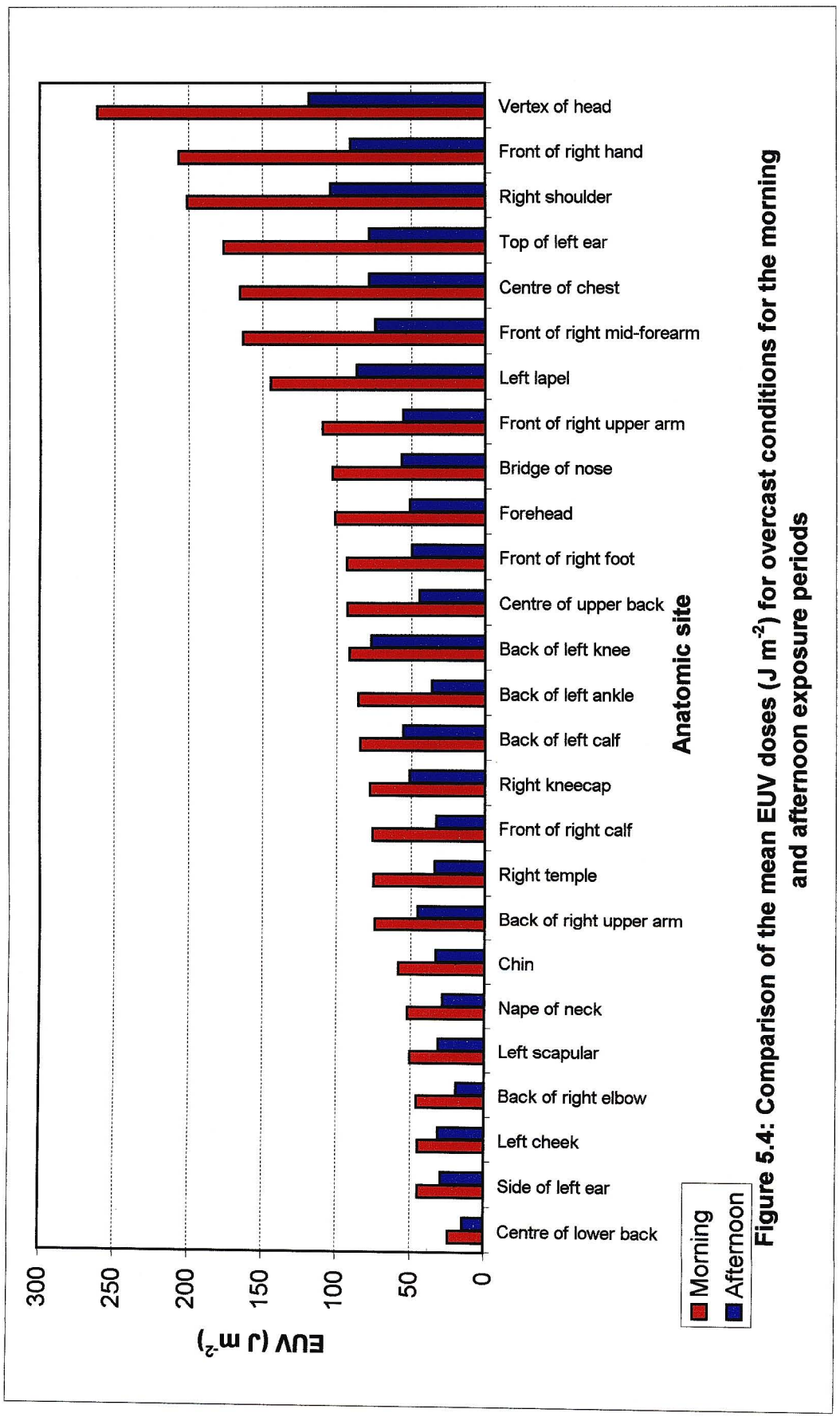


Figure 5.4: Comparison of the mean EUV doses (J m^{-2}) for overcast conditions for the morning and afternoon exposure periods

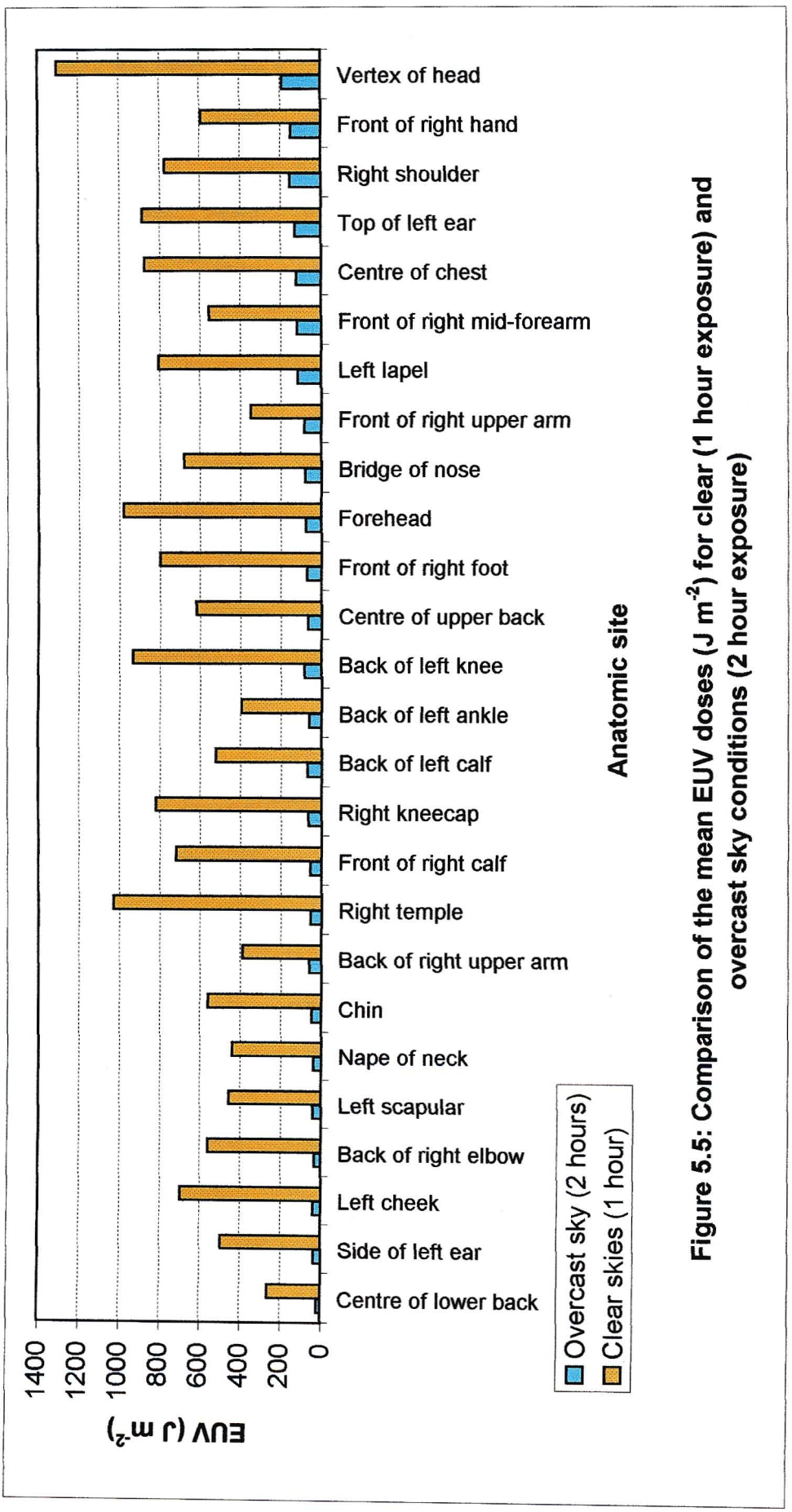


Figure 5.5: Comparison of the mean EUV doses (J m^{-2}) for clear (1 hour exposure) and overcast sky conditions (2 hour exposure)

cover when the solar disk is not obscured. Cloud cover should therefore not be used as a single protective measure against receiving high doses of EUV since the variability of cloud cover is not conducive for advising individuals on conditions that offer the most protection.

5.4 Influence of solar zenith angle on the anatomical distribution of erythemal ultraviolet radiation

The solar zenith angle, the angle between the zenith and the apparent position of the sun, is an important factor contributing towards the relative anatomical distribution of EUV. Parrish *et al.* (1978) state that the anatomic sites that receive the most EUV when the solar zenith angle is small, are the unprotected parts of the head, i.e. a balding head, the rim of the ears, forehead, nose, lower lip, cheeks and chin, the shoulders, back of the neck, upper arm and to a lesser extent, the arms and hands. The chest, back, abdomen and legs are more exposed when the solar zenith angle is large.

Solar zenith angles for the five clear sky days ranged from 60.5° - 55.0 ° between 11:00 and 12:00 and 53.5° - 53.0° between 12:30 and 13:30. The minimum solar zenith angle of 53.0°, at which point the sun was at its highest, was at approximately 12:57. The sun was thus relatively high in the sky and the sites indicated by Parrish *et al.* (1978), i.e. the vertex of the head, and other protruding parts of the facial area were indeed found to receive the highest EUV doses in this study as indicated in Table 5.1.

Figure 5.6 presents a diagram of a standing human body projected in the direction of the solar beam for four solar altitudes. The images were derived from a study conducted in the early 1970s of 25 male and female subjects photographed from 19 different angles in relation to the direct solar beam (Monteith, 1973). The projection of the direct solar beam on a standing person for solar altitudes of 63° falls upon the vertex of the head, the shoulders and the tops of the feet, independent of the body's orientation towards the sun itself. The 90° rotation of the mannequin to the right every 15 minutes ensured that the front, left side, back and right side of the body were exposed for equal periods to the direct solar beam and subsequently the source of

ultraviolet radiation. Since the mannequin was exposed around local noon when the solar altitude was greater than at least 30°, the lower back and legs evidently received less EUV than the top of the shoulder, the arms and the tops of the feet.

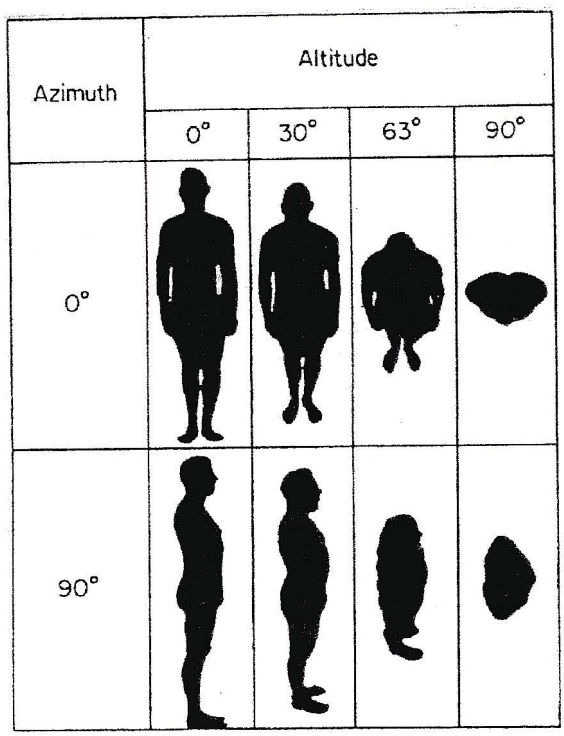


Figure 5.6: An upright human body projected in the direction of the direct solar beam for four solar altitudes (Source: Monteith, 1973: 44)

Kimlin *et al.* (1998) state that with large solar zenith angles the EUV exposure to vertical surfaces relative to horizontal surfaces is higher. In summer, smaller solar zenith angles result in a higher EUV dose to horizontal surfaces. In winter, with larger solar zenith angles, the difference in EUV doses between the vertical and horizontal surfaces is reduced. This study shows that in winter, vertical surfaces of an upright person received approximately 50% of the EUV dose received by the vertex while potentially shaded horizontal surfaces received approximately 80% of the vertex. It is possible that in summer, the difference between these percentages may be accentuated such that horizontal surfaces receive an even higher percentage of the vertex than vertical surfaces.

Measurements from the YES UVB-1 pyranometer indicate that in summer, solar zenith angles range between approximately 26.5° - 21.5° between 11:00 and 12:00 and

approximately 21.5° - 29.5° between 12:00 and 13:30, with a minimum solar zenith angle at 12:04. These are relatively low solar zenith angles compared to winter values. This may have implications for human health since most people tend to spend more time outdoors during summer than during winter and when upright, would possibly receive relatively higher EUV doses to horizontal sites such as the shoulders and tops of the feet.

5.5 Anatomical distribution of erythemal ultraviolet radiation and skin cancer

Figure 5.7 presents a superimposition of the zones in which NMSC is commonly found in light-skinned individuals onto the pre-determined EUV zones identified in Table 5.2. The front of the arms received an EUV dose of approximately 63% of the vertex value and therefore a relatively high EUV dose when compared with the rest of the body. The front of the arms is a predominant site for the occurrence of NMSC, together with the lower limbs and facial area that received approximately 40% and 25% of the vertex value respectively. These anatomic sites are also frequently exposed to ultraviolet radiation, particularly in Durban, where maximum summer temperatures are usually above 24°C and people tend to wear short sleeve shirts, shorts and skirts. Evidently, the geometry of the direct solar beam on the body of an upright human supports the association of ultraviolet radiation with NMSC.

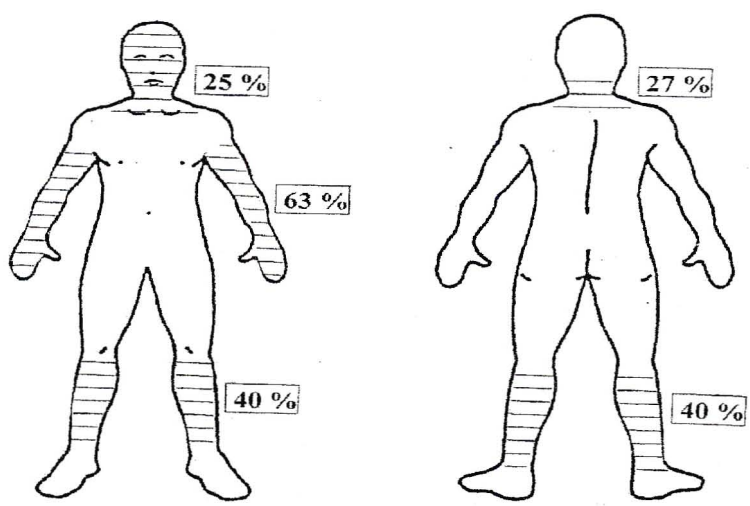


Figure 5.7: The anatomical distribution of EUV for various anatomic sites as a percentage of the vertex (%) and NMSC in light-skinned individuals (shaded regions)

The nape of the neck is also a common site for NMSC, however, the results of this study do not confirm that it is a particularly vulnerable anatomic site in terms of ultraviolet radiation exposure. It received an EUV dose equivalent to approximately 27% of the vertex which may have been on account of shading by the back of the lower head and the angular orientation of the part of the neck where the PSF strip was attached. Figure 5.8 illustrates those parts of the body where MMSC is frequently diagnosed in light-skinned individuals. The anatomic sites tend to be the trunk of males and the lower limbs of females (Diffey, 1991). According to the EUV zones, the lower limbs received an EUV dose of approximately 40% of the vertex, which is a moderate EUV dose relative to the shoulders and the vertex. The upper trunk or chest received an EUV dose of approximately 75% of the vertex value, however, the quantified EUV dose may have been overestimated due to the protruding nature of the mannequin's chest. MMSC therefore tends to occur on anatomic sites that are infrequently exposed to ultraviolet radiation. This is in accordance with the intermittent exposure hypothesis discussed in Section 2.5, stating that MMSC is not always situated on anatomic sites that are frequently exposed to ultraviolet radiation.

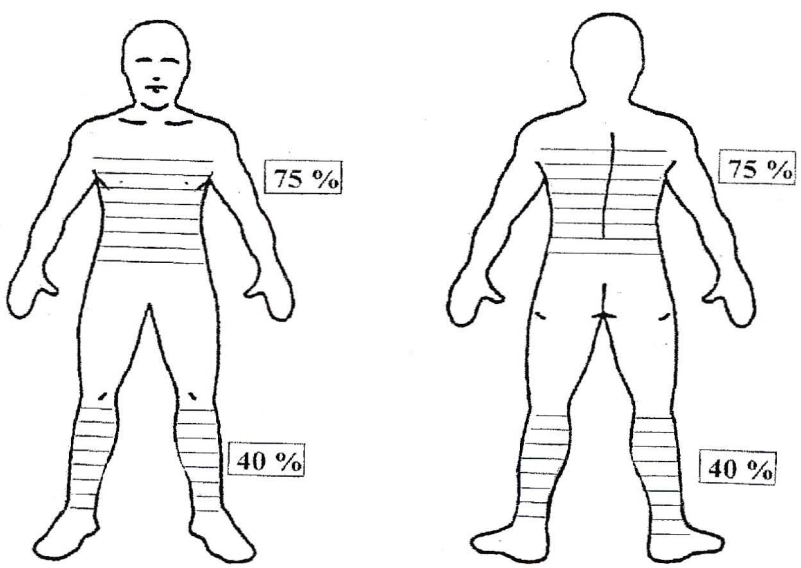


Figure 5.8: The anatomical distribution of EUV for various anatomic sites as a percentage of the vertex (%) and MMSC in light-skinned individuals (shaded regions)

5.6 Ambient erythemal ultraviolet radiation and the human body

The ambient EUV for only four of the five clear sky days, on account of instrument failure, is illustrated in Figures 5.1. The low EUV conditions, ranging between approximately 0 - 0.08 W m^{-2} are typical of those experienced during winter in Durban. These 'winter' EUV conditions may be compared with the 'summer' EUV conditions illustrated in Figure 4.1. Maximum noon EUV levels range between approximately 0.06 - 0.08 W m^{-2} in winter and 0.25 - 0.35 W m^{-2} in summer.

The anatomical distribution of EUV expressed as a percentage of the total daily ambient EUV as measured by the YES UVB-1 pyranometer over the five day period for clear sky conditions is presented in Table 5.4. As the mannequin was exposed for two hours each day, the percentages for the anatomic sites of the total daily ambient EUV conditions were relatively small, ranging between 2.6 - 19.8%.

Table 5.4 also presents the 26 anatomic EUV doses as a percentage of the mean PSF control that was exposed for the same period as the mannequin but on a horizontal, un-shaded surface. It also includes the anatomic EUV doses as a percentage of the ambient EUV for the exact periods of exposure calculated using the YES UVB-1 pyranometer measurements. The results show that most anatomic sites receive less than the amount of EUV incident upon the earth's surface for the exact periods of exposure. The vertex may have received more than the PSF control on account of the difference in height between the mannequin's head and the positioning of the PSF control approximately one metre above ground level.

The remaining anatomic sites received between 14.6 - 90.4% of the PSF control. The top of the left ear, a horizontal anatomic site received 52.6% of the control compared with a much lower percentage (12.2%) on the side of the ear. Although not common, cases of NMSC have been diagnosed on the upper part of the ear, particularly on actinically damaged skin (Gawkrodger, 1992). The facial area received approximately 50% of the PSF control, while the lower legs received approximately 48% and the arms 55%. Vertical surfaces tended to receive approximately 50% of the PSF control while horizontal surfaces received more than 80% of the PSF control.

Table 5.4: EUV doses at 26 different anatomic sites as a percentage of the mean total daily ambient EUV and the PSF control

Anatomic site	Percentage of total daily ambient EUV (%)	Percentage of ambient EUV for the exact periods of exposure (%)	Percentage of PSF control (%)
Vertex of the head	19.87	106.13	110.80
Forehead	11.17	60.83	62.20
Bridge of nose	11.06	59.42	61.70
Chin	8.22	43.19	45.90
Left cheek	6.14	34.53	34.30
Right temple	7.36	38.52	41.00
Top of left ear	9.45	49.30	52.60
Side of left ear	3.79	19.89	21.20
Left lapel	12.33	66.55	68.80
Right shoulder	16.22	85.48	90.40
Right scapular	5.58	30.03	31.10
Front of right mid-forearm	13.59	70.36	75.80
Front of right hand	13.30	77.96	74.30
Front of right upper arm	12.18	64.22	67.90
Back of right upper arm	5.96	31.44	33.20
Back of right elbow	4.49	24.43	25.10
Nape of neck	5.42	28.61	30.20
Centre of upper back	7.05	37.87	39.30
Centre of lower back	2.63	14.55	14.60
Centre of chest	15.04	79.89	83.80
Right kneecap	7.83	40.89	43.70
Back of left knee	9.72	51.41	54.20
Front of right mid-calf	7.39	38.48	41.20
Back of left mid-calf	8.10	43.34	45.20
Back of left ankle	8.09	42.97	45.20
Front of right foot	9.26	47.74	51.60

Diffey (1991) compared the mean fraction of ambient EUV received at six anatomic sites for the exact periods of exposure using both a mannequin and living subjects (Table 5.5). The results compare well with those obtained for the cheek and upper arm in this particular study. The EUV doses of the shoulder and chest were overestimated

while that of the lower back was significantly underestimated. People tend to move around in a variety of positions, preferring to turn away from the sun and often stooping forward rather than standing completely upright. This may account for some of the differences between the results obtained using a mannequin compared with living subjects as illustrated in this study where the mannequin employed was positioned in such a manner that the lower back was considerably shadowed by the shoulders.

Table 5.5: Comparison between the anatomic EUV doses as a percentage of ambient EUV of a rotating mannequin and living subjects for a study conducted in England and this study (After: Diffey, 1991)

Anatomic site	Mannequin (% of ambient EUV for exact periods of exposure)	Living subjects (% of ambient EUV for exact periods of exposure)	Mannequin (This study) (% of ambient EUV measured using PFS for exact periods of exposure)
Cheek	31	15 – 47	34
Shoulder	75	66 – 70	90
Lower sternum	66	44 – 46	83
Lumbar spine	47	58 – 71	14
Upper arm	52	59 – 66	67
Dorsum of hand	42	24 – 78	74

The quantification of the anatomical distribution of EUV using a mannequin provides for an understanding of the effect of orientation of an anatomic site towards the direct solar beam on EUV dose by eliminating factors such as human movement and behaviour. It is then possible to relate these results to the EUV doses received by the children and adolescents in this study and to outline recommendations regarding protective mechanisms and behaviour alterations.

5.7 Anatomical erythemal ultraviolet radiation distribution of children and adolescents in Durban and protective strategies

The anatomical distribution of EUV, observed in Section 5.2, identified certain anatomic sites as being more vulnerable than others to ultraviolet radiation exposure. In order to integrate the findings of Section 5.2 with the subjects' PSFB doses, the

anatomic EUV doses were calculated as a percentage of the lapel (Table 5.1) and, using the mean PSFB dose for all subjects on all days of the study period (1.04 MED units), EUV doses for all of their anatomic sites were deduced. The results are presented in Figure 5.9 and confirm that the vertex, shoulders, facial area, chest, hands and front of the legs received relatively EUV doses. Excluding the chest, all of the anatomic sites identified as being susceptible to relatively high EUV doses are sites that are frequently exposed to the sun due to the nature of clothing worn by children and adolescents.

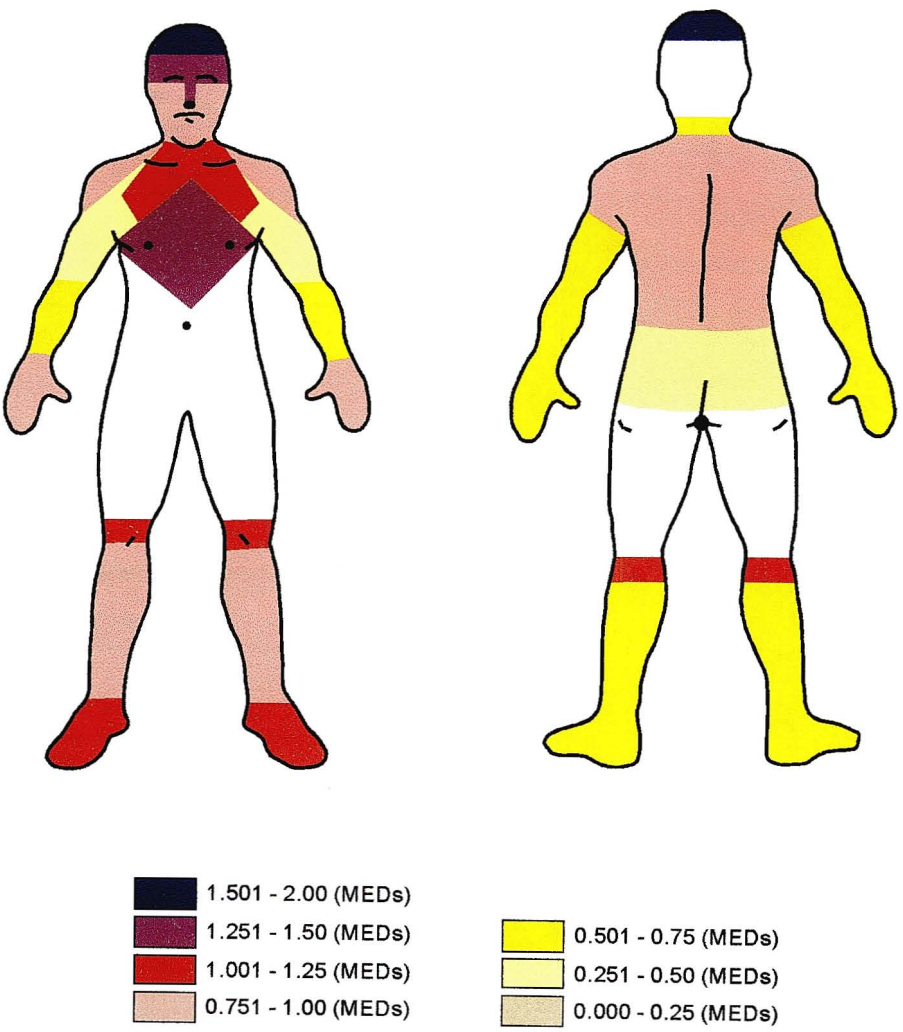


Figure 5.9: Anatomical distribution of EUV for children and adolescents in Durban according to their lapel PSFB dose

In Durban, a typical school uniform consists of long pants (males), a skirt (females) or shorts (younger children) with a short sleeve shirt in summer. A long sleeve shirt is usually worn in winter, however, winter maximum air temperatures for Durban may

exceed 25°C and short sleeve shirts are often worn outside of school hours. Therefore, the arms are likely to be frequently exposed to ultraviolet radiation. The vertex of the head potentially receives a high EUV dose, however, hair affords the skin a certain amount of protection against ultraviolet radiation.

A layer of clothing usually protects the shoulders and the chest unless the individual wears a sleeveless shirt or swimming costume. These anatomic sites are then protected according to the nature of the fabric. Parisi *et al.* (2000c) suggests that the primary factor affecting ultraviolet radiation transmission is the weave structure and colour of the factor. Other parameters include the fabric type, mass, cover, stretch, quality and fabric layering (Gies *et al.*, 1994). All of these factors influence the ultraviolet protection factor (UPF) of the garment. Most garments do not provide total ultraviolet radiation protection, however, polyester fabric has been found to provide two to three times more protection than other fabrics (Mills *et al.*, 1997). The darker the fabric the higher the UPF since the presence and quantity of dye molecules in the fabric affects the transmission of ultraviolet radiation through the fabric.

Parisi *et al.* (2000c) found that black garments, in both wet and dry states, reduced the amount of ultraviolet radiation incident on the underlying skin by greater proportions at all wavelengths compared to white garments. The density and mass of the fabric also increases its UPF, e.g. knit fabrics and spandex (Mills *et al.*, 1997). The public needs to be informed on the varying degree of protection offered by different garments owing to the nature of their fabric. It has been suggested that all garments should be equipped with an additional swing tag that describes the UPF properties of the garment and emphasises the necessity of a combination of several ultraviolet radiation protection strategies to minimise ultraviolet radiation of the skin.

A number of the children and adolescents monitored in this study spent time after school hours and on weekends swimming, where girls wore a full swimming costume or bikini and boys wore swimming trunks. Neither of these two garments protected vulnerable anatomic sites such as the shoulder, arms and facial area. Analysis of the journals kept by those subjects who received the highest PSFB doses journals showed that none of these subjects were wearing clothing that protected their forearms, hands,

and faces from ultraviolet radiation nor were they making use of sunscreen during these exposure periods. In terms of the high PSFB doses that they received during these exposure periods, there is clearly an acute risk of them having experienced erythema on these exposed anatomic sites.

Consequently, a number of recommendations may be made regarding protective measures that children and adolescents in Durban could adopt to minimise the health risks of overexposure to ultraviolet radiation. It is strongly advised that children apply and re-apply sunscreen on a daily basis to the facial area, arms, hands and legs, and to any other part of the body when it is not protected by a layer of clothing. A hat with a wide brim should be worn whenever they are outside to afford the facial area additional protection against the direct solar beam and they should attempt to find shade as often as possible. Other behaviour alterations that can be adopted to reduce human ultraviolet radiation exposure when outdoors include:

- Spend minimal time outdoors between 10:00 - 15:00 when ambient ultraviolet radiation levels are at there highest during the day (Weinstock *et al.*, 1989).
- Participate in outdoors activities in the early morning and late afternoon when ambient ultraviolet radiation levels are lower than compared to the levels experienced around solar noon (WHO, 1995).
- Apply sunscreen, on a daily basis, evenly and thickly to all exposed parts of the body and reapply during the course of the day (Weinstock *et al.*, 1989).
- When time has to be spent outdoors between 10:00 - 15:00 individuals should attempt to find shaded locations where the view of the sky above is negligible.
- Sports and school breaks should be rescheduled to times before or after 10:00 - 15:00 or alternatively should be conducted in shaded locations or indoor environments (Koh and Geller, 1999).
- Hats and ultraviolet radiation protective clothing should be worn on a daily basis, especially during the summer months in Durban, and particularly when spending extended periods of time outdoors.
- Deliberate suntanning should be avoided (Borland, 1999).

Communication strategies attempting to raise ultraviolet radiation awareness and alter sun-related behaviour patterns may be implemented at an individual or collective level. The primary individual ultraviolet radiation protective mechanism is to limit ultraviolet radiation exposure during periods of high ambient ultraviolet radiation levels. Collective initiatives may include construction of shade structures and the planting of trees, alteration of school time tables with respect to outdoor exposure times and the enforcement of simple rules such as 'no hat, no sunscreen, no outdoor activities' at pre-school and primary school levels in particular.

The recommendations made above apply to both light-skinned and medium-skinned children and adolescents. Although the implications of overexposure to ultraviolet radiation are different for different skin types, there are adverse impacts that apply to all skin types ranging from wrinkling of the skin to MMSC.

The primary prevention against high ultraviolet radiation exposure requires an intervention in behaviour in order to reduce ultraviolet radiation exposure. Making use of sunscreen, a hat and staying out of the direct solar beam by finding shade are measures that require an alteration in attitude and lifestyle. Sports events, outdoor classes and extramural activities should be scheduled before 10:00 and after 15:00 wherever possible. In light of the relationship between childhood exposure to ultraviolet radiation and the development of skin cancer, it is advisable that children learn to adopt these positive changes as early in their lives as possible.

It is recommended that the ultraviolet radiation protective strategies outlined above be implemented into the South Africa school system. This school system is currently being revised and an outcomes-based educational programme is being implemented. This may be favourable timing for the introduction of modules relating to ultraviolet radiation, its detrimental health effects and 'safe-sun' behaviour, in order to minimise childhood and adolescent ultraviolet radiation exposure and reduce the likelihood of associated adverse health impacts most often experienced during adulthood.

Chapter Six
CONCLUSION

6.1 Summary

It is widely held that ultraviolet radiation exposure, when taken to levels far in excess of that required for adequate synthesis of vitamin D, is a cause of various adverse health impacts. Cumulative and intermittent exposure to ultraviolet radiation have been shown to be risk factors for the induction of skin cancer during adulthood. Childhood ultraviolet radiation exposure plays an important role in accentuating this risk of developing skin cancer in later years. Quantification of childhood and adolescence ultraviolet radiation doses and exposure patterns is necessary to suggest preventative efforts to minimise these risks.

The aim of this study was to investigate the ultraviolet radiation exposure of children and adolescents in Durban. Measurements of personal ultraviolet radiation exposure were made in late summer 2001 for 30 children and adolescents using ultraviolet radiation-sensitive polysulphone film badges attached to the lapel site. Personal ultraviolet radiation exposure records were kept by the children and adolescents and were used to determine the effects of age, gender, skin type and activities on the ultraviolet radiation doses of the children and adolescents. Concurrent meteorological data associated with ultraviolet radiation exposure were obtained. Comparisons were made with ambient ultraviolet radiation conditions monitored by a YES UVB-1 pyranometer. A mannequin was used to determine the anatomical distribution of ultraviolet radiation under clear and overcast conditions and the results were related to the ultraviolet radiation doses of the children and adolescents.

The mean daily erythemal ultraviolet radiation dose for all the children and adolescents over the 7 day study period was 1.04 MED units. The median daily erythemal ultraviolet radiation (EUV) dose was 0.57 MED units which is less than the critical value of 1 MED unit. These values are relatively low compared with Brisbane, Australia (Gies *et al.*, 1998) and were attributed to the particularly high ambient temperatures and humidity levels experienced during the study period. However, it

was noted that they exceeded the occupational daily limit set by the International Radiation Protection Association of 0.15 MED units as well as exceeding values calculated by Diffey *et al.* (1996) in a study of children of similar ages in England. Although the mean EUV dose was relatively low, cumulative ultraviolet radiation exposures of this quantity may serve to enhance the risk of skin cancer during adulthood. Maximum daily EUV doses exceeded 7.22 MED units and would have induced minimal, painful and severe erythema depending on individual skin type.

The children and adolescent's daily EUV doses were calculated as a percentage of the total daily ambient EUV for weekdays and the weekend where the weekend percentages were greater than the weekday percentages. The mean for all days was 4.58%. The frequency distribution of the daily EUV doses as a percentage of the total daily ambient EUV for all subjects on all days showed that 83.8% lay below 9% of the total daily ambient EUV. The daily EUV doses were also calculated as a percentage of the ambient EUV for the exact periods of exposure, as indicated in the personal ultraviolet radiation exposure journals, where the mean percentage was 18.6%. In this manner, the time not spent outdoors was eliminated and therefore reflects the degree of shading and random movement of the individual. This percentage was similar to that calculated for the daily EUV doses as a percentage of the ambient EUV for the exact periods of exposure weighted by 0.5 for shade on days when all exposure periods were in the shade (18.2%).

A more sophisticated technique was applied to eliminate factors such as varying ambient EUV, shade and orientation of the anatomic site by using a calculation suggested by Parisi (pers. comm., 2001). The mean EUV dose as a percentage of the theoretical EUV dose was 64.6%, suggesting that the more parameters used in estimating individual EUV dose, the more accurate the EUV dose.

In order to provide an estimate of the relationship between annual ambient EUV levels and daily EUV doses of children and adolescents during one year in Durban, the mean daily EUV dose as a percentage of the total daily ambient EUV dose (4.6%), was used in conjunction with the total daily ambient EUV (MED units) for 2000. The MED values required to induce minimal, painful and severe erythema were

superimposed on these values and the number of days during the year when children and adolescents are likely to experience erythema were deduced.

The daily EUV doses of the children and adolescents were also considered as a function of five variables: age, gender, skin type, behaviour (timing and duration of exposure; day of the week) and activity. Children between the ages of 4 - 9 years received on average higher EUV doses than adolescents, although no significant relationship was found between EUV dose and age. It was noteworthy that the variability amongst the children and adolescents of formal school going age (>7 years) was less during the week than that of the younger age group, most likely on account of the more structured school day in the older age groups. There was no statistically significant relationship between the EUV doses of male and female individuals, or the EUV doses of light-skinned and medium-skinned individuals. The mean EUV dose of males was slightly higher than that of females on account of longer outdoor exposure periods experienced by males. This suggests that males may be more susceptible to the risk of skin cancer than females.

Examination of the personal ultraviolet radiation exposure journals allowed for an analysis of their daily behaviour patterns. Time spent outdoors was generally greater on the weekend than weekdays. The mean length of time spent outdoors for all subjects for all days of the study was 2.3 hours per day. Although a relatively small portion of the day, the timing of these exposure periods is critical in determining the intensity and severity of the EUV dose received by an individual. Frequent outdoor ultraviolet radiation exposures on weekdays were between 10:00 - 11:00 and 12:00 - 13:00 according to school break times and falling within the period of the day when ambient EUV levels are highest. Personal EUV doses were potentially high, however, remained less than ambient EUV levels on account of shading, behaviour, orientation of the body towards the direct solar beam and random movement.

The variability of behaviour amongst children and adolescents was identified as the fundamental factor influencing personal EUV dose, exposure and distribution by anatomic site. Typical behaviour patterns during school term when this study was undertaken were associated with the daily school structure including two breaks and extramural activities. These included swimming, cricket, golf, cycling, tennis, karate,

sun tanning, ball skills, observing sports events and playing outdoors. Since the children and adolescent's PSFBs measured their total daily EUV dose, it was not possible to determine the amount of EUV received during particular activities. However, when considering the ten highest daily EUV doses from all age groups for all days, swimming was one of the most frequently pursued activities. The exposure durations on the days with the ten highest EUV doses were all longer than one hour, however, the highest daily EUV dose did not correspond with the longest exposure duration between 10:00 and 15:00. This highlights the complexity of understanding additional factors such as the nature of the activity, timing and duration of exposure, orientation of the anatomic site and degree of shading in relation to the severity of ultraviolet radiation-induced damage.

In order to further investigate the relationship between individual EUV dose and activity, three activities, i.e. swimming, walking and tennis, were conducted on one clear sky day and the hourly EUV doses for each was compared to the ambient EUV dose for that hour to determine an activity factor. These activity factors were then compared with those derived in similar studies and found to compare well. The activity factors may then be applied to a determined activity model in order to estimate individual EUV dose for a particular activity. This innovative model has the potential for use as a predictor of individual EUV dose and consequently may help to emphasise the importance of responsible behaviour in terms of ultraviolet radiation exposure.

The anatomical distribution of EUV was measured at 26 anatomic sites on the surface of a mannequin for two hours around local noon on five clear sky conditions and four hours around local noon on two overcast days. For both clear and overcast conditions, horizontal anatomic sites, i.e. shoulders and vertex of the head, received the highest EUV doses as a result of their orientation towards the direct solar beam. Vertical sites including the hands, arms and face also received relatively high EUV doses. These exposure ratios showed little variation under overcast conditions, although EUV doses were generally reduced compared to clear sky conditions. The solar zenith angle was noted as being an important factor where small solar zenith angles during summer tend to result in higher EUV doses on horizontally oriented anatomic sites.

The anatomical distribution of EUV was also related to that of malignant melanoma skin cancer (MMSC) and non-melanoma skin cancer (NMSC). Results showed that anatomic sites with potentially high EUV doses, i.e. lower limbs, arms and facial area, were also predominant sites for the occurrence of NMSC thereby supporting the association of ultraviolet radiation with NMSC. MMSC tends to occur on anatomic sites that are infrequently exposed to ultraviolet radiation, however, it was difficult to support this theory due to the protruding nature of the mannequin's chest which led to an overestimation of this site's EUV dose.

The anatomical distribution of EUV was also related to ambient EUV. As the mannequin was exposed for a relatively small portion of the day, the EUV doses as a percentage of the total daily ambient EUV were small, ranging between 2.6 - 19.8%. However, the EUV doses as a percentage of the ambient EUV for the exact periods of exposure were larger and ranged between approximately 10 - 90%. The anatomical distribution of EUV was then related to children and adolescents in Durban. Typical items of clothing worn by these individuals were considered in relation to those anatomic sites identified as being most vulnerable to high ultraviolet radiation exposure. Recommendations were then made and it was strongly advised that children and adolescents in Durban apply and re-apply an effective sunscreen on a daily basis to the face, arms, hands and legs, and to any anatomic site when it is not protected by a layer of clothing. A hat should be worn whenever outdoors and shade should be found whenever possible. In view of the relationship between childhood and adolescence exposure to ultraviolet radiation and the development of skin cancer, it is advisable that children learn to adopt such changes as early in their lives as possible.

6.2 Recommendations

The study of personal ultraviolet radiation exposure in South Africa is a relatively under-researched subject where this is the first study of its kind to be undertaken and there are many aspects requiring investigation. This research needs to provide a foundation for the implementation of effective communication strategies to inform people, particularly children and adolescents, of the health risks associated with exposure to ultraviolet radiation. Suggestions for conducting a similar study in the future in terms of experimental design include:

- The use of two PSFBs per day to alleviate the inaccuracy of the PSF measurements when ΔA_{330} exceeds 0.45 absorbance units.
- The use of a waterproof mount for the PSFB to allow for use during water sports and rainy weather.
- The use of one PSF control per day for the duration of the study when subjects are wearing the PSFBs for comparative purposes against the YES UVB-1 pyranometer.
- Recruitment of a larger subject base, based on a random selection procedure that includes dark-skinned individuals to allow for consideration of their exposure habits and an attempt at assessing the associated health risks.
- This study recruited volunteers deemed diligent at keeping records and wearing the PSFBs to participate in the study. Future studies conducted in South Africa may want to consider making use of a random selection process to ensure inclusion of all sectors of society.
- The use of a time-line instead of a journal which includes additional information such as detail pertaining to the issue of shade conditions and the wearing of hats.

The following broad recommendations are made for future research in this field:

- A long-term investigation of personal ultraviolet radiation exposure in order to calculate, through the application of various equations, the risk of skin cancer for an individual.
- The quantification of the ultraviolet radiation dose received by school goers during break times and consideration of optimal restructuring of these break times in order to reduce ultraviolet radiation exposure during periods when ambient ultraviolet radiation levels are high.
- Further studies pertaining to the relationship between individual EUV dose and activity.
- Ultraviolet radiation protective agents and mechanisms should be introduced as early as a pre-school and primary school level to minimise the risk of overexposure to ultraviolet radiation and the associated consequences.

- To develop and evaluate ultraviolet radiation protection agents and mechanisms that may sustainably modify overexposure to ultraviolet radiation during childhood and adolescence.
- Case-control studies of South African residents diagnosed with skin cancer to determine their ultraviolet radiation exposure patterns and other risk factors that may substantiate either the childhood exposure hypothesis or intermittent exposure hypothesis.
- To assess the feasibility of using nevi as indicators of a potentially high risk of skin cancer and then to implement such techniques amongst children and adolescents in Durban and other parts of South Africa to increase awareness of personal risk-factors.
- To initiate participatory education programmes within Durban communities and schools to increase awareness of the adverse health impacts associated with overexposure to ultraviolet radiation.
- To create a public information service to broadcast daily ultraviolet radiation indices and additional information to inform the public of necessary precautions to ensure their protection against overexposure to ultraviolet radiation. Radio and television broadcasts, updated web sites and cellular communication services may all be efficient means of relaying important information to the public.

This study has provided objective data on the magnitude and range of ultraviolet radiation doses received by children and adolescents over a one-week period during the school term in late summer in Durban. Whilst the results may be extrapolated for the behaviour of South African children and adolescents, they may not necessarily be appropriate to young people of other countries. The finding that children and adolescents do not behave as a homogenous group may have significant implications for the future design of personal ultraviolet radiation studies.

REFERENCES

Aida, M. (1977) Scattering of solar radiation as a function of cloud dimensions and orientation, *Journal of Quantitative Spectroscopy and Radiative Transfer*, 17, 303 – 310.

Armstrong, B.K. (1994) Stratospheric ozone and health, *International Journal of Epidemiology*, 23 (5), 873 – 885.

Basset, A., Liautaud, B. and Ndiaye, B. (eds) (1986) *Dermatology of Black Skin*, Oxford University Press, Oxford, United Kingdom.

Bodeker, G.E. and McKenzie, R.L. (1996) An algorithm for inferring surface UV irradiance including cloud effects, *Journal of Applied Meteorology*, 35, 1860 – 1877.

Bodeker, G.E. and Scourfield, M.W.J. (1998) Estimated past and future variability in UV radiation in South Africa based on trends in total column ozone, *South African Journal of Science*, 94, 24 – 32.

Bodhaine, B.A., McKenzie, R.L., Johnston, P.V., Hofmann, D.J., Dutton, E.G., Schnell, R.C., Barnes, J.E., Ryan, S.C. and Kotkamp, M. (1996) New ultraviolet spectroradiometer measurements at Mauna Loa Observatory, *Geophysical Research Letters*, 23 (16), 2121 – 2124.

Bodhaine, B.A., Dutton, E.G., McKenzie, R.L. and Johnston, P.V. (1998) Calibrating broadband instruments: ozone and solar zenith angle dependence, *Journal of Atmospheric and Oceanic Technology*, 15, 916 – 926.

Bordewijk, J.A., Slaper, H., Reinen, H.J.A.M. and Schlamann, E. (1995) Total solar radiation and the influence of clouds and aerosols on the biologically effective ultraviolet radiation, *Geophysical Research Letters*, 22 (16), 2151 – 2154.

Borland, R. (1999) Understanding and measuring human responses to sun exposure, *Cancer Forum*, 20, 198 – 204.

Commission Internationale d'Eclairage (1987) A reference action spectrum for ultraviolet induced erythema in human skin, *C.I.E.J.*, 6, 17 – 22.

Commission Internationale de L'Eclairage (1997) Technical report – Standard Erythemal Dose (A review), C.I.E.J., 125, ISBN 3 900 734 800 X.

Committee on Causes and Effects of Changes in Stratospheric Ozone (1983*) The Causes and Effects of Changes in Stratospheric Ozone: Update 1983*, Environmental Studies Board, Commission on Physical Science, Mathematics and Resources, National Research Council. National Academy Press, USA

Conti, C.J., Slaga, T.J. and Klein-Szanto, A.J.P. (eds) (1989) *Carcinogenesis: A Comprehensive Survey (Volume II) Skin Tumours Experimental and Clinical Aspects*, Raven Press, USA.

Davis, A., Deane, G.H.W. and Diffey, B.L. (1976) Possible dosimeter for ultraviolet radiation, *Nature*, 261, 169 – 170.

Diab, R.D. (2000) The ozone monitoring and research project final report for the period April 1999 – March 2000, Report submitted to the Department of Environmental Affairs and Tourism, Pretoria, South Africa.

Diab, R.D., Barsby, J., Bodeker, G., Scourfield, M.W.J. and Salter, L. (1992) Satellite observations of total column ozone above South Africa, *South African Geographical Journal*, 74, 13 – 18.

Diffey, B.L. (1986) Ultraviolet radiation dosimetry and Measurement, In Orton, C.G. (ed) (1986) *Radiation Dosimetry: Physical and Biological Aspects*, Plenum Publishing, New York. Chapter 5, 243 – 319.

Diffey, B.L. (1990) New trends in photodosimetry, In Lowe, N.J. and Shaath, N.A. (eds) (1990) *Sunscreens: Development, Evaluation and Regulatory Aspects*, Marcel Dekker Inc, New York. Chapter 7, 93 – 98.

Diffey, B.L. (1991) Solar ultraviolet radiation effects on biological systems, *Physical Medical Biology*, 36 (3), 299 – 328.

Diffey, B.L. (1992) Stratospheric ozone depletion and the risk of non-melanoma skin cancer in a British population, *Physical Medical Biology*, 37 (12), 2267 – 2279.

Diffey, B.L., Gibson, C.J., Haylock, R. and McKinlay, A.F. (1996) Outdoor ultraviolet exposure of children and adolescents, *British Journal of Dermatology*, 134, 1030 – 1034.

Diffey, B.L., Kerwin, M. and Davis, A. (1977) The anatomical distribution of sunlight, *British Journal of Dermatology*, 97, 407 – 409.

Diffey, B.L., Larko, O. and Swanbeck, G. (1982) UV-B doses received during different outdoor activities and UV-B treatment of psoriasis, *British Journal of Dermatology*, 106, 33 – 41.

Diffey, B.L. and Saunders, P.J. (1995) Behaviour outdoors and its effects on personal ultraviolet exposure rate measured using an ambulatory data-logging dosimeter, *Photochemistry and Photobiology*, 61 (6), 615 – 618.

Diffey, B.L., Tate, T.J. and Davis, A. (1979) Solar dosimetry of the face: the relationship of natural ultraviolet radiation exposure to Basal cell carcinoma localisation, *Physical Medical Biology*, 24 (5), 931 – 939.

Dubin, N., Pasternack, B.S. and Moseson, M. (1990) Simultaneous assessment of risk factors for malignant melanoma and non-melanoma skin cancer lesions, with emphasis on sun exposure and related variables, *International Journal of Epidemiology*, 19 (4), 811 – 819.

Duigan, B.L. (1995) Ozone, ultraviolet radiation and skin burn times, Unpublished M.Sc. thesis, University of Natal, Durban, 1 – 300.

Duigan, B.L., Scourfield, M.W.J. and Stefanski jnr, B. (1995) Surface UVB irradiance measurements at Durban during 1993, *South African Journal of Science*, 91, 394 – 399.

Elwood, J.M., Gallagher, R.P., Hill, G.B., Spinelli, J.J., Pearson, J.C.G. and Threlfall, W. (1984) Pigmentation and skin reaction to sun as risk factors for cutaneous melanoma: Western Canada Melanoma Study, *British Medical Journal*, 288, 99 – 102.

Elwood, J.M., Whitehead, S.M., Davison, J., Stewart, M. and Galt, M (1990) Malignant melanoma in England: Risks associated with naevi, freckles, social class, hair colour and sunburn, *International Journal of Epidemiology*, 19 (4), 801 – 810.

Epstein, J.H. (1990) Biological Effect of Sunlight, In Lowe, N.J. and Shaath, N.A. (eds) (1990) *Sunscreens: Development, Evaluation and Regulatory Aspects*, Marcel Dekker Inc, New York. Chapter 3, 3 – 50.

Estupinan, J.G., Raman, S., Crescenti, G.H. Streicher, J.J. and Barnard, W.F. (1996) Effects of clouds and haze on UV-B radiation, *Journal of Geophysical Research.* 101 (D11), 16807 – 16816.

Fleming, I.D., Barnawell, J.R., Burlison, P.E. and Rankin, J.S. (1975) Skin cancer in black patients, *Cancer*, 35, 600 – 605.

Frederick, J.E. and Snell, H.E. (1990) Tropospheric influence on solar ultraviolet radiation: the role of clouds, *Journal of Climate*, 3, 373 – 381.

Gallagher, R.P. (ed) (1986) *Recent Results in Cancer Research – Epidemiology of Malignant Melanoma,* Springer - Verlag, Germany.

Gawkrodger, D.J. (1992) *An Illustrated Colour Text: Dermatology*, Churchill Livingstone, Edinburgh..

Gies, H.P., Roy, C.R., Elliot, G. and Zongli, W. (1994) Ultraviolet radiation protection factors for clothing, *Health Physics*, 67 (2), 131 – 139.

Gies, H.P., Roy, C., Toomey, S., MacLennan, R. and Watson, M. (1995) Solar ultraviolet radiation exposures of three groups of outdoor workers on the Sunshine Coast, Queensland. *Photochemistry and Photobiology*, 62 (6), 1015 – 1021.

Gies, H.P., Roy, C., Toomey, S., MacLennan, R. and Watson, M. (1998) Solar ultraviolet radiation exposures of school children at three locations in Queensland, *Photochemistry and Photobiology*, 68 (1), 78 – 83.

Goettsch, W., Garssen, J., Slob, W., de Gruil, F.R. and Van Loveren, H. (1998) Risk Assessment for the harmful effects of UVB radiation on the immuniological resistance to infectious diseases, *Environmental Health Perspectives*, 106 (2), 1 – 25.

Grant, R.H., Heisler, G.M. and Gao, W. (2000) Estimation of pedestrian level UV-B exposure under trees in suburban environments, Second Internet Conference on Photochemistry and Photobiology, 16 July – 7 September 1999.

Green, A., MacLennan, R. and Siskind, V. (1985) Common acquired naevi and the risk of malignant melanoma, *International Journal of Cancer*, 35, 297 – 300.

Grossman, L. (1997) Epidemiology of ultraviolet-DNA repair capacity and human cancer, *Environmental Health Perspectives*, 105 (4), 1 – 18.

Guy, C.Y. (2000) A health risk assessment of ultraviolet radiation in Durban, Unpublished B. Soc. Sc. (Hons) thesis, University of Natal, Durban, 1 - 198.

Harm, W. (1980) *Biological Effects of Ultraviolet Radiation*, Cambridge University Press, USA.

Henriksen, T., Dahlback, A., Larsen, S.H.H. and Moan, J. (1990) Ultraviolet radiation and skin cancer: effect of an ozone layer depletion. *Photochemistry and Photobiology*, 54 (5), 579 – 582.

Herlihy, E., Gies, P.H., Roy, C.R. and Jones, M. (1994) Personal dosimetry of solar radiation for different outdoor activities, *Photochemistry and Photobiology*, 60 (3), 288 – 294.

Herman, J.R. and McKenzie, R.L. (1998) Ultraviolet radiation at the earth's surface, World Meteorological Organisation Global Ozone Research and Monitoring Project Report, No. 44. Scientific Assessment of Ozone Depletion: 1998, 9.1 – 9.36.

Herman, J.R., Bhartia, P.K., Ziemke, J., Ahmad, Z. and Larko, D. (1996) UV-B increases (1979 – 1992) from decreases in total ozone, *Geophysical Research Letters*, 23, 2117 – 2120.

Holly, E.A., Kelly, J.W., Shpall, S.N. and Chiu, S-H. (1987) Number of melanocytic nevi as a major risk factor for malignant melanoma, *Journal of the American Academy of Dermatology*, 17 (3), 460 – 468.

Holman, C.D.J., Gibson, I.M., Stenphenson, M. and Armstrong, B.K. (1983) Ultraviolet irradiation of human body sites in relation to occupation and outdoor activity: field studies using personal UVR dosimeters, *Clinical and Experimental Dermatology*, 8, 269 – 277.

Holman, C.D.J., Armstrong, B.K. and Heenan, P.J. (1986) Relationship of cutaneous malignant melanoma to individual sunlight-exposure habits, *Journal of the National Cancer Institute*, 76, 403 – 414.

Horneck, G. (1995) Quantification of the biological effectiveness of environmental ultraviolet radiation, *Photochemistry and Photobiology*, 31, 43 – 49.

Instruction Manual: Model UV-B-1 ultraviolet pyranometer, Yankee Environmental Systems Inc, Turners Falls, MA 01376.

Jahan, M.S. (1990) Physics of optics: terminology and units, In Lowe, N.J. and Shaath, N.A. (eds) (1990) *Sunscreens: Development, Evaluation and Regulatory Aspects*, Marcel Dekker Inc, New York.

Jones, R.R. (1987) Ozone Depletion and Cancer Risk, The Lancet, 22 August 1987.

Josefsson, W. and Landelius, T. (2000) Effects of clouds on UV irradiance as estimated from cloud amount, cloud type, precipitation, global radiation and sunshine duration, *Journal of Geophysical Research*, 105 (D4), 4927 – 4935.

Kalicharran, S., Diab, R.D. and Sokolic, F. (1993) Trends in total ozone over southern African stations between 1979 and 1991, *Geophysical Research Letters*, 20 (2), 2877 – 2880.

Kimlin, M.G. and Parisi, A.V. (2000) Effect of meal break times on solar UV exposure to schoolchildren in a Southeast Queensland summer month, Unpublished paper.

Kimlin, M.G., Parisi, A.V. and Wong, J.C.F. (1997) Quantification of personal solar ultraviolet exposure of outdoor workers, indoor workers and adolescents at two locations in Southeast Queensland, *Photodermatology, Photoimmunology and Photomedecine*, 14, 1 – 5.

Kimlin, M.G., Parisi, A.V. and Wong, J.C.F. (1998) The facial distribution of erythemal ultraviolet exposure in south-east Queensland, *Physical Medical Biology*, 43, 231 – 240.

Kimlin, M.G., Parisi, A.V. and Wong, J.C.F. (2000) The whole human body distribution of solar erythemal ultraviolet radiation, Proceedings of the First Internet Conference on Photochemistry and Photobiology, November 17 – December 19, 1997, Internet Photochemistry and Photobiology.

Koh, H.K. and Geller, A.C. (1999) Melanoma and skin cancer control: an international perspective, *Cancer Control Journal*, 2 (5), 1 – 15.

Lee, J.A.H. (1989) The relationship between malignant melanoma of skin and exposure to sunlight, *Photochemistry and Photobiology*, 50 (4), 493 – 496.

Lew, R. and Rosenthal, F. (1988) Daily exposure of adolescents to ultraviolet light, *Journal of Investigative Dermatology*, 90.

Longstreth, J., de Gruijl, F.R., Kripke, M.L., Abseck, S., Anrnold, F., Slaper, H.I., Velders, G., Takizawa, Y., van der Leun, J.C. (1998) Health Risks, In: van der Leun, J.C., Tang, X., Tevini, M. (eds) *Environmental effects of ozone depletion: 1998 Assessment*, UNEP, Nairobi, Kenya, 28 – 61.

Lowe, N.J. and Shaath, N.A. (eds) (1990) *Sunscreens: Development, Evaluation and Regulatory Aspects,* Marcel Dekker Inc, New York.

Lubin, D. and Frederick, J.E. (1991) The ultraviolet radiation environment of the Antarctic Peninsula: the roles of ozone and cloud cover, *Journal of Applied Meteorology*, 30, 478 – 492.

MacKie, R.M. and Aitchison T. (1982) Severe sunburn and subsequent risk of cutaneous malignant melanoma in Scotland, *British Journal of Cancer*, 46, 955 – 960.

MacKie, R.M. (1989) *Skin cancer: an illustrated guide to the aetiology, clinical features, pathology and management of benign and malignant cutaneous tumours,* Martin Dunitz, UK.

Madronich, S. (1993) UV radiation in the natural and perturbed atmosphere, In: Tevini, M. (ed) *UV-B Radiation and Ozone Depletion – Effects on Humans, Animals, Plants, Micro-organisms and Materials,* Lewis Publishers, USA.

Madronich, S., McKenzie, R.L., Caldwell, M.M. and Bjorn, L.O. (1995) Changes in ultraviolet radiation reaching the earth's surface, *Ambio*, 24 (3), 143 – 152.

Malik, M.O.A., Hidyatalla, A., Daoud, E.H. and El Hassan, A.M. (1974) Superficial cancer in the Sudan – a study of 1225 primary malignant superficial tumours, *British Journal of Cancer*, 30, 355 – 364.

Marks, R., Jolley, D., Lectas, S. and Foley, P. (1990) The role of childhood exposure to sunlight in the development of solar keratoses and non-melanocytic skin cancer, *The Medical Journal of Australia*, 152, 62 – 66.

McKenzie, R.L. and Bodeker G.E. (1999) UV and ozone: An Update, *Water and Atmosphere*, 4 (11), 7 – 11.

McKenzie, R.L. and Elwood, J.M. (1990) Intensity of solar ultraviolet radiation and its implications for skin cancer, *New Zealand Medical Journal*, 103, 152 – 154.

McKenzie, R.L., Matthews, W.A. and Johnston, P.V. (1991). The relationship between erythemal ultraviolet radiation and ozone, derived from spectral irradiance measurements, *Geophysical Research Letters*, 18 (12), 2269 – 2272.

McKenzie, R.L., Paulin, K.J. and Kotkamp, M. (1998) Erythemal UV irradiances at Lauder, New Zealand: relationship between horizontal and normal incidence, *Photochemistry and Photobiology*, 66 (5), 683 – 689.

Meloni, D., Casale, G.R., Siani, A.M., Palmieri, S. and Cappellani, F. (2000) Solar UV dose patterns in Italy, *Photochemistry and Photobiology*, 71 (6), 681 – 690.

Mills, C.J., Trouton, K. and Gibbons, L. (1997) Symposium Report: 2nd symposium on UV-related diseases, *Chronic Diseases in Canada*, 18 (1), 1 – 10.

Moise, A.F., Buttner, P.G. and Harrison, S.L. (1999a) Exposure at school, *Photochemistry and Photobiology*, 70, 269 – 279.

Moise, A.F., Gies, H.P. and Harrison, S.L. (1999b) Estimation of the annual solar ultraviolet radiation exposure dose of infants and small children in Tropical Queensland, Australia, *Photochemistry and Photobiology*, 69 (4), 457 – 463.

Monteith, J.L. (1973) *Principles of Environmental Physics*, William Clowes and Sons, London.

Nack, M.L. and Green, A.E.S. (1974) Influence of clouds, haze and smog on the middle ultraviolet reaching the ground, *Applied Optics*, 13 (10), 2405 – 2415.

National Institute of Health (NIH) (1989) Sunlight, ultraviolet radiation and the skin, National Institute of Health Consensus Development Conference Statement, 8 – 10 May, 7, (8), 1 – 29.

National Research Council (1983) Causes and effects of changes in stratospheric ozone: update 1983, Environmental studies board, commission on physical sciences, mathematics and resources, National Academy Press, Washington D. C.

Nemeth, P., Toth, Z. and Nagy, Z. (1996) Effect of weather conditions on UV-B radiation reaching the earth's surface, *Photochemistry and Photobiology*, 32, 177 – 181.

Occupational Health and Safety Series (1985) *Protection of workers from power frequency electric and magnetic fields: a practical guide*, International Non-ionising Radiation Committee of the International Radiation Protection Association in collaboration with the International Labour Organisation, Geneva.

Oettle, A.G. (1964) Cancer in Africa, especially in regions south of the Sahara, *Journal of the National Cancer Institute*, 33 (3), 383 – 426.

Orton, C.G. (ed) (1986) *Radiation Dosimetry: Physical and Biological Aspects*, Plenum Publishing, New York.

O'Riordan, D.L., Stanton, W.R., Eyeson-Annan, M., Gies, P. and Rey, C. (2000) Correlations between reported and measured ultraviolet radiation exposure of others and young children, *Photochemistry and Photobiology*, 71 (1), 60 – 64.

Osterlind, A., Tucker, M.A., Stone, B.J. and Jensen, O.M. (1988) The Danish case-control study of cuntaneous malignant melanoma: Importance of UV-light exposure, *International Journal of Cancer*, 42, 319 – 324.

Parisi, A.V., Green, A. and Kimlin, M.G. (2001) Diffuse solar ultraviolet radiation and implications for preventing human eye damage, *Photochemistry and Photobiology*, 73 (2), 135 – 139.

Parisi, A.V. and Kimlin, M.G. (1999) Comparison of the spectral biologically effective solar ultraviolet in adjacent tree shade and sun, *Physical Medical Biology*, 44, 2071 – 2080.

Parisi, A.V. and Kimlin, M.G. (2000) Estimate of annual ultraviolet-A exposure in cars in Australia, *Radiation Protection Dosimetry*, 90 (4), 409 – 416.

Parisi, A.V., Meldrum, L.R. and Kimlin, M.G. (2000a) Polysulphone film thickness and its effects in ultraviolet radiation dosimetry, Protection against the hazards of UVR, Internet Conference, 18 January – 5 February 1999.

Parisi, A.V., Kimlin, M.G., Wong, J.C.F. and Wilson, M. (2000b) Diffuse component of the solar ultraviolet radiation in tree shade, Second Internet Conference on Photochemistry and Photobiology, 16 July – 7 September 1999.

Parisi, A.V., Kimlin, M.G., Mulheran, L., Meldrum, L.R. and Randall, C. (2000c) Field based measurements of personal erythemal ultraviolet exposure through a common summer garment, *Photodermatology, Photoimmunology and Photomedecine*, 16, 1 – 5.

Parisi, A.V. and Wong, J.C.F. (1999) Human exposure to filtered solar ultraviolet radiation, Proceedings of the First Internet Conference on Photochemistry and Photobiology, 17 November – 19 December 1997.

Parrish, J.A., Anderson, R.R., Urbach, F. and Pitts, D. (eds) (1978) *UVA: Biological Effects of Ultraviolet Radiation with Emphasis on Human Responses to Longwave Ultraviolet Radiation,* Plenum Press, USA.

Parrish, J. A., Jaenicke, K.F. and Anderson, R.R. (1982) Erythema and melagenesis action spectra of normal human skin, *Photochemistry and Photobiology*, 36, 187 – 191.

Pathak, M.A. (1990) Intrinsic photoprotection in human skin, In Lowe, N.J. and Shaath, N.A. (eds) (1990) *Sunscreens: Development, Evaluation and Regulatory Aspects*, Marcel Dekker Inc, New York. Chapter 5, 73 – 83.

Pawin, H. (1999) *UV Light and Skin: Necessity for Efficient UVA Photoprotection for Human Skin,* Galderma Laboratories, France.

Pegum, J.S. and Baker, H. (1979) *Dermatology*, Lowe and Brydone, UK.

Phillips, R. (1983) *Sources and Applications of Ultraviolet Radiation*, Academic Press, UK.

Prause, A.R., Scourfield, M.W.J., Bodeker, G.E. and Diab, R.D. (1999) Surface UVB irradiance and total column ozone above SANAE, Antarctica, *South African Geographical Journal*, 95, 26 – 30.

Renaud, A. and Staehelin, J. (2000) Influence of snow and clouds on erythemal UV radiation: analysis of Swiss measurements and comparison with models, *Journal of Geophysical Research*, 105 (D4), 4961 – 4969.

Sabburg, J. and Wong, J. (2000) The effects of clouds on enhancing UVB irradiance at the earth's surface: a one year study, *Geophysical Research Letters*, 27 (20), 3337 – 3340.

SAS/STAT User's Guide (1990) Version 6, Fourth Edition, Volume 1, SAS Institute Inc, North Carolina.

SAWB (1996) *Climate of South Africa WB42,* Government Printer, Pretoria.

Seckmeyer, G., Erb, R. and Arnold, A. (1996) Transmittance of a cloud is wavelength dependent in the UV-range, *Geophysics Research Letters*, 23 (20), 2753 – 2755.

Shapiro, M.P., Keen, P., Cohen, L. and Murray, J.F. (1953) Skin cancer in South African Bantus, *British Journal of Cancer*, 7 (1), 45 – 57.

Sorahan, J. and Grimley R.P. (1985) The aetiological significance of sunlight and fluorescent lighting in malignant melanoma: a case-control study, *British Journal of Cancer*, 52, 765 – 769.

Stern, R.S, Weinstein, M.C. and Baker, S.G. (1986) Risk reduction for non-melanoma skin cancer with childhood sunscreen use, *Archive of Dermatology*, 122, 537 – 545.

Taylor, H.G. (1989) The biological effects of UV-B on the eye, *Photochemistry and Photobiology*, 50 (4), 489 – 492.

Tevini, M. (1993) *UV-B Radiation and Ozone Depletion – Effects on Humans, Animals, Plants, Micro-organisms and Materials,* Lewis Publishers, USA.

Taalas, P., Amanatidis, G.T. and Heikkila, A. (2000) European Conference on Atmospheric UV Radiation: Overview, *Journal of Geophysical Research*, 105 (4), 4777 – 4785.

Truhan, A.P. (1991) Sun protection in childhood, *Clinical Pediatrics*, 30 (12), 676 – 681.

Urbach, F. (1989a) Potential effects of altered solar ultraviolet radiation on human skin cancer, *Photochemistry and Photobiology*, 50 (4), 507 – 513.

Urbach, F. (1989b) The biological effects of increased ultraviolet radiation: an update, *Photochemistry and Photobiology*, 50 (4), 439 – 441.

Webb, A.R. (1995) Measuring ultraviolet radiation: a discussion of dosimeter properties, uses and limitations, *Journal of Photochemistry and Photobiology*, 31, 9 – 13.

Webb, A.R. (1998) *UVB Instrumentation and Applications*, Gordon and Breach Science Publishers, Amsterdam.

Weihs, P., Webb, A.R., Hutchinson, S.J. and Middleton, G.W. (2000) Measurements of the diffuse UV sky radiance during broken cloud conditions, *Journal of Geophysical Research*, 105 (4), 4937 – 4944.

Weinstock, M.A., Colditz, G.A., Willet, W.C., Stampfer, M.J., Bronstein, B.R., Mihm jnr, M.C. and Speizer, F.E. (1989) Non-familial cutaneous melanoma incidence in women associated with sun exposure before 20 years of age, *Pediatrics*, 84 (2), 199 – 204.

Wong, J.C. and Parisi, A.V. (1999) Assessment of ultraviolet radiation exposures in photobiological experiments, Protection against the hazards of UVR, Internet Conference, 18 January – 5 February 1999.

Zerefos, C. S. and Bais, A. F. (1995*) Solar Ultraviolet Radiation: Modelling, Measurements and Effects*, Series 1: Global Environmental Change, vol. 52, Proceedings of the NATO Advanced Study Institute on Solar Ultraviolet Radiation, held in Halkidiki, Greece, October 2 – 11, 1995.

PERSONAL COMMUNICATION

Bodeker, G. (2001) National Institute of Water and Atmosphere, Private bag 50061, Omakau, Central Otago, New Zealand.

Diffey, B.L. (2001) Regional Medical Physics Department, Newcastle General Hospital, Newcastle NE4 6BE, UK.

Parisi, A.V. (2001) Centre for Astronomy and Atmospheric Research, Faculty of Sciences, University of Southern Queensland, Toowoomba 4350, Australia.

WEB SITE ADDRESSES

CANSA (2001) CANSA Research, http://www.cansa.co.za/registry.

Broomfield (2001) http://www.healthanswers.com.

Definition of the Hawthorne effect (2001) www.inverson software.com/sociology/ hawthorne_effect.htm.

Environmental Health Perspectives (EHP) (1998) Cataract development, 106, December 12, http://ehpnet.niehs.nih.gov/docs/1998/106-12/forum.htm.

Lapenta, J.R. (2001) Dermatologo, http://www.archer.med.br/de/dmtcpl.html.

NASA (2001) Goddard Space Flight Centre, http://toms.gsfc.nasa.gov/.

Ohio State University Fact Sheet (OSUFS) (1998) Ultraviolet radiation, http://www.ag.ohio-state.edu/~ohioline/cd-fact/0199.html.

Optic Tech Inc (2001) http://www.Safesun.com/scientific.html.

SAWS (2001) UVB monitored at Pretoria, Cape Town and Durban between 1994 – 1998, http://www.ngo.grida.no/soesa/nsoer/indicator/fig1_9a (and b and c).htm.

Scotto, J. (2001) Non-melanoma skin cancer, Internet article for the National Cancer Institute, Biostatistics Branch, Division of Cancer Etiology, National Cancer Institute, USA, http://www.healthgoods.com/Education/Health_Information/Cancer_Rates_and _Risks/skin_cancer.htm.

World Health Organisation (WHO) (1995) Intersun: The global UV project, http://www.who.int/peh-uv/publications/english/who_ehg_95-17.htm.

APPENDIX I

Listed below is a table of the calibration data referred to in Section 3.4 where Pre-A, Post-A and ΔA_{330} are defined in the text.

Table 1. Calibration of PSF data

Badge No.	Pre-A_{330}	Post-A_{330}	ΔA_{330}	EUV (J m^{-2})	Badge No.	Pre-A_{330}	Post-A_{330}	ΔA_{330}	EUV (J m^{-2})
1	0.212	0.269	0.057	83.56	51	0.223	0.538	0.315	675.03
2	0.217	0.281	0.064	70.23	52	0.231	0.558	0.327	669.80
3	0.204	0.272	0.068	82.96	53	0.165	0.497	0.332	748.04
4	0.197	0.269	0.072	78.73	54	0.197	0.542	0.345	755.95
5	0.203	0.297	0.094	76.34	55	0.176	0.525	0.349	829.65
6	0.198	0.298	0.100	182.30	56	0.199	0.549	0.350	787.64
7	0.200	0.309	0.109	182.30	57	0.224	0.575	0.351	737.62
8	0.240	0.364	0.124	157.45	58	0.204	0.559	0.355	910.24
9	0.212	0.338	0.126	165.93	59	0.239	0.590	0.357	802.85
10	0.190	0.317	0.127	85.91	60	0.213	0.578	0.365	838.63
11	0.198	0.328	0.130	152.68	61	0.250	0.622	0.372	868.07
12	0.185	0.316	0.131	140.45	62	0.198	0.571	0.373	990.85
13	0.190	0.322	0.132	167.12	63	0.206	0.589	0.383	921.61
14	0.182	0.348	0.166	250.69	64	0.200	0.614	0.414	1138.22
15	0.216	0.383	0.167	246.99	65	0.200	0.627	0.427	1138.22
16	0.217	0.384	0.167	234.28					
17	0.189	0.357	0.168	226.23					
18	0.198	0.367	0.169	184.14					
19	0.194	0.365	0.171	214.22					
20	0.207	0.379	0.172	171.82					
21	0.455	0.542	0.187	311.11					
22	0.186	0.383	0.197	334.25					
23	0.223	0.427	0.204	299.78					
24	0.198	0.406	0.208	414.53					
25	0.187	0.397	0.210	256.80					
26	0.203	0.418	0.215	328.04					
27	0.200	0.415	0.215	414.53					
28	0.197	0.414	0.217	362.76					
29	0.184	0.402	0.218	417.76					
30	0.232	0.459	0.227	385.20					
31	0.200	0.429	0.229	287.98					
32	0.209	0.448	0.239	406.34					
33	0.192	0.440	0.248	341.78					
34	0.211	0.459	0.248	370.54					
35	0.205	0.457	0.252	437.55					
36	0.177	0.429	0.252	501.27					
37	0.233	0.497	0.264	459.29					
38	0.198	0.463	0.265	441.30					
39	0.216	0.483	0.267	425.78					
40	0.201	0.473	0.272	727.70					
41	0.200	0.473	0.273	444.91					
42	0.178	0.459	0.281	515.83					
43	0.190	0.472	0.282	583.851					
44	0.232	0.514	0.282	530.64					
45	0.200	0.487	0.287	727.70					
46	0.209	0.500	0.291	484.63					
47	0.172	0.476	0.304	666.43					
48	0.241	0.549	0.308	601.98					
49	0.216	0.526	0.310	509.78					
50	0.213	0.527	0.314	594.11					

APPENDIX II

Included below are copies of the letter and consent forms used in this study.

(a) Letter to the school principal

RESEARCH PROJECT AIMED AT MONITORING THE ULTRAVIOLET RADIATION EXPOSURE OF CHILDREN AND ADOLESCENTS IN DURBAN

Thank you for agreeing to allow your school to participate in this study. Through the application of polysulphone film badges, accurate estimates will be made of the amount of solar ultraviolet radiation received by children and adolescents in Durban. Such information will enable us to make more accurate statements regarding solar ultraviolet radiation exposure and the likely risk of developing various skin cancers.

A total of 30 children and adolescents have been selected from four local schools. Three age groups will be monitored: 4 – 6 years, 7 – 9 years and 13 – 14 years. Each individual will be required to wear one polysulphone film badge per day for 7 days. The badge will be attached to the lapel region of the body, situated between the shoulder and the chest. The badge is to be worn by each individual from the time that they wake up until the time that the sun has completely disappeared. The only time that the badge is to be removed is during bathing and swimming, at which times the badge is to placed in a dry, un-shaded location in close proximity to the individual. All of the children and adolescents participating in the study will be strongly advised not to touch the film in the centre of the badge and not to immerse the badge in water or any other liquid. Once the badge has been used it must be returned to the envelope in which it was provided. Prior to use the badges must be kept in the provided envelopes and not exposed to any light. There is no safety hazard in handling or usage of the polysulphone film badges.

Each individual will be required to fill in a journal for the 7 days that they will be wearing the badges. In the case of the very young individuals, the teacher and parent will take responsibility for completing the journal. The journal will include information on the time at which different activities were undertaken, whether the child was indoors or outdoors, whether they were in the shade or the sun, what they were wearing and whether they were wearing sunscreen. The information in the journal will allow for an investigation of the effects of behaviour patterns, age, gender and race on the ultraviolet radiation exposure of each individual. Once the research is complete each school will receive a report discussing the results of the study.

Many thanks for agreeing to participate in this study that will provide valuable information for the benefit of the public health of our country.

Yours sincerely
Caradee Guy

(b) Letter to the parent/guardian/teacher

RESEARCH PROJECT AIMED AT MONITORING THE ULTRAVIOLET RADIATION EXPOSURE OF CHILDREN AND ADOLESCENTS IN DURBAN

Thank you for agreeing to allow your child to participate in this study. Through the application of polysulphone film badges, accurate estimates will be made of the amount of solar ultraviolet radiation received by children and adolescents in Durban. Such information will enable us to make more accurate statements regarding solar ultraviolet radiation exposure and the likely risk of developing various skin cancers.

A total of 30 children and adolescents have been selected from four local schools. Three age groups will be monitored: 4 – 6 years, 7 – 9 years and 13 – 14 years. Each individual will be required to wear one polysulphone film badge per day for 7 days. The badge will be attached to the lapel region of the body, situated between the shoulder and the chest. The badge is to be worn by each individual from the time that they wake up until the time that the sun has completely disappeared. The only time that the badge is to be removed is during bathing and swimming, at which times the badge is to placed in a dry, un-shaded location in close proximity to the individual. All of the children and adolescents participating in the study will be strongly advised not to touch the

film in the centre of the badge and not to immerse the badge in water or any other liquid. Once the badge has been used it must be returned to the envelope in which it was provided. Prior to use the badges must be kept in the provided envelopes and not exposed to any light. There is no safety hazard in handling or usage of the polysulphone film badges.

Each individual will be required to fill in a journal for the 7 days that they will be wearing the badges. In the case of the very young individuals, the teacher and parent will take responsibility for completing the journal. The journal will include information on the time at which different activities were undertaken, whether the child was indoors or outdoors, whether they were in the shade or the sun, what they were wearing and whether they were wearing sunscreen. The information in the journal will allow for an investigation of the effects of behaviour patterns, age, gender and race on the ultraviolet radiation exposure of each individual. Once the research is complete each school will receive a report discussing the results of the study.

Please read the enclosed information sheet and complete the consent form on behalf of your child and return it to the researcher via the school contact teacher. Please note that participation in this study is voluntary and you may at any time choose to withdraw your child from the study. Many thanks for agreeing to participate in this study that will provide valuable information for the benefit of the public health of our country.

Yours sincerely
Caradee Guy

(c) Consent form for parents/guardians of subjects

I, _____ (NAME)

here by consent to my child participating in the study to monitor the ultraviolet radiation exposure of children and adolescents in Durban.

I also acknowledge that I have understood all that is required of my child is to wear the provided polysulphone film badge during the course of his/her daily activities during sunlight hours and to record his/her daily activities in the provided journal. This is to be carried out for a total of seven days.

I acknowledge that I understand the precautions required in handling the polysulphone film badges as explained to me by Caradee Guy and described in the information section of the journal provided, and that there is no safety hazard in handling or usage of this film.

I acknowledge that I understand the contents of this form, including the information provided in the information section.

As the PARENT/GUARDIAN (DELETE THAT WHICH IS NOT APPLICABLE) I freely consent to the participation of

_____(NAME OF CHILD)
in this study.

I am aware that I may withdraw my consent at any time without prejudice.

Signed: _____ Date: _____
(Parent/Guardian)

Signed: _____ Date: _____
(Witness)

Signed: _____ Date: _____
(Researcher)

(d) Letter to participant

RESEARCH PROJECT AIMED AT MONITORING THE ULTRAVIOLET RADIATION EXPOSURE OF INDIVIDUALS PARTICIPATING IN VARIOUS OUTDOOR LEISURE ACTIVITIES

Thank you for agreeing to participate in this study. Through the application of polysulphone film badges, accurate estimates will be made of the amount of solar ultraviolet radiation received by an individual during a particular outdoor activity.

Four adult volunteers have volunteered to partake in four activities on one clear-sky day during late spring in Durban. Each individual will wear one polysulphone film badge attached to the hand for 1-hour periods from 8:00 – 16:00. Each polysulphone film badge is to be removed after 1-hour has lapsed and replaced in the labeled, light-impervious envelope. Prior to use the badges must remain in the designated envelopes. The badge's aperture containing the ultraviolet radiation-sensitive film should not be touched nor damaged in any way. There is no safety hazard in the handling or usage of the polysulphone film badges. The individuals will participate in four specified activities and will be permitted to take breaks for the use of ablutions and nourishment. The time and duration of these breaks will be noted.

Please read the enclosed information sheet and complete the consent form and return it to the researcher. Please note that participation in this study is voluntary and you may at any time choose to withdraw from the study.

Many thanks for agreeing to participate in this study that will provide valuable information for the benefit of the public health of our country.

Yours sincerely
Caradee Guy

(e) Consent form for participant

I, _____ (NAME)

hereby consent to participating in the study to monitor the ultraviolet radiation exposure of individuals during various outdoor leisure activities in Durban.

I also acknowledge that I have understood all that is required of me is to participate in four outdoor leisure activities on one day and wear a polysulphone film badge attached to my hand.

I acknowledge that I understand the precautions required in handling the polysulphone film badges as explained to me by Caradee Guy and described in the Information Sheet provided, and that there is no safety hazard in handling or usage of this film.

I acknowledge that I understand the contents of this form, including the information provided in the Information Sheet. I am aware that I may withdraw my consent at any time without prejudice.

Signed: _____ Date: _____
(Participant)

Signed: _____ Date: _____
(Witness)

Signed: _____ Date: _____
(Researcher)

APPENDIX III

Listed below are the PSFB doses of the subjects who participated in this study.

Table 2. PSFB doses of all subjects

Badge no.	Subject no.	Pre-A_{330}	Post-A_{330}	ΔA_{330}	EUV (J m^{-2})	Damaged and/or unused
1	27	0.213	0.489	0.276	525.671	
2		0.185	0.289	0.104	107.397	
3		0.197	0.369	0.172	236.911	
4		0.237	0.441	0.204	314.079	
5		0.189	0.375	0.186	269.394	
6		0.179	0.294	0.115	125.169	
7		0.188	0.480	0.292	579.829	
8	11	0.220	0.338	0.118	130.229	
9		0.250	0.407	0.157	204.311	
10		0.209	0.366	0.157	204.311	
11		0.219	0.319	0.100	101.239	
12		0.257	0.376	0.119	131.936	
13		0.183	0.183	0.000	0.000	Unused
14		0.133	0.133	0.000	0.000	Unused
15	28	0.235	0.461	0.226	373.156	
16		0.233	0.317	0.084	78.227	
17		0.190	0.257	0.067	56.622	
18		0.200	0.377	0.177	248.284	
19		0.241	0.348	0.107	112.123	
20		0.195	0.279	0.084	78.227	
21		0.254	0.272	0.018	10.740	
22	21	0.199	0.295	0.096	95.243	
23		0.202	0.332	0.130	151.381	
24		0.249	0.356	0.107	112.123	
25		0.213	0.355	0.082	75.534	
26		0.229	0.311	0.082	75.534	
27		0.198	0.265	0.067	56.622	
28		0.177	0.289	0.112	120.201	
29	16	0.214	0.417	0.203	311.511	
30		0.186	0.226	0.038	26.527	
31		0.240	0.333	0.093	90.852	
32		0.218	0.308	0.090	86.553	
33		0.244	0.354	0.110	116.939	
34		0.168	0.377	0.189	276.614	
35		0.228	0.454	0.226	373.156	
36	25	0.222	0.262	0.040	28.329	Damaged
37		0.190	0.203	0.013	7.427	Damaged
38		0.199	0.276	0.077	68.976	
39		0.175	0.260	0.085	79.590	
40		0.226	0.267	0.041	29.245	
41		0.230	0.261	0.031	20.541	
42		0.206	0.206	0.000	0.000	
43	12	0.191	0.326	0.135	160.626	
44		0.217	0.344	0.127	145.957	
45		0.246	0.352	0.106	110.537	
46		0.248	0.533	0.285	555.815	
47		0.193	0.311	0.118	130.229	
48		0.212	0.212	0.000	0.000	Unused
49		0.167	0.285	0.098	98.221	
50	6	0.227	0.479	0.252	449.301	
51		0.211	0.520	0.309	640.215	
52		0.197	0.530	0.333	730.456	

53		0.218	0.406	0.188	274.198	
54		0.257	0.316	0.059	47.468	
55		0.224	0.425	0.201	306.404	
56		0.232	0.323	0.091	87.976	
57	1	0.221	0.221	0.000	0.000	Lost
58		0.198	0.273	0.075	66.424	
59		0.258	0.302	0.044	32.054	
60		0.213	0.293	0.080	72.880	
61		0.209	0.275	0.066	0.000	Unused
62		0.220	0.220	0.000	0.000	Unused
63		0.231	0.231	0.000	0.000	
64	7	0.250	0.361	0.111	118.565	
65		0.246	0.502	0.256	461.623	
66		0.216	0.327	0.111	118.565	
67		0.198	0.438	0.240	413.305	
68		0.244	0.389	0.145	179.874	
69		0.265	0.358	0.093	90.852	
70		0.155	0.470	0.315	662.228	
71	8	0.236	0.307	0.071	61.442	
72		0.194	0.346	0.152	193.952	
73		0.243	0.318	0.075	66.424	
74		0.223	0.345	0.122	137.118	
75		0.207	0.301	0.094	92.306	
76		0.174	0.367	0.193	286.382	
77		0.215	0.295	0.080	72.880	
78	22	0.156	0.343	0.187	271.791	
79		0.179	0.222	0.043	31.108	
80		0.190	0.315	0.125	142.391	
81		0.196	0.290	0.094	92.306	
82		0.250	0.405	0.155	200.137	
83		0.222	0.452	0.230	384.425	
84		0.243	0.644	0.401	1017.850	
85	23	0.240	0.306	0.066	55.442	
86		0.229	0.345	0.116	126.846	
87		0.204	0.466	0.262	480.412	
88		0.247	0.324	0.077	68.976	
89		0.243	0.398	0.155	200.137	
90		0.184	0.308	0.124	140.623	
91		0.188	0.250	0.062	0.000	Unused
92	26	0.229	0.568	0.339	753.928	
93		0.176	0.259	0.083	76.875	
94		0.237	0.345	0.108	113.718	
95		0.176	0.231	0.055	43.135	
96		0.265	0.000	0.000	0.000	Unused
97		0.262	0.000	0.000	0.000	Unused
98		0.158	0.504	0.346	781.774	
99	15	0.243	0.346	0.103	105.842	
100		0.154	0.283	0.129	149.563	
101		0.204	0.307	0.103	105.843	
102		0.214	0.318	0.104	107.397	
103		0.143	0.243	0.100	101.239	
104		0.233	0.632	0.399	1008.728	
105		0.153	0.301	0.148	185.847	
106	14	0.164	0.305	0.141	172.053	
107		0.197	0.326	0.129	149.563	
108		0.199	0.320	0.121	135.381	
109		0.234	0.354	0.120	133.653	
110		0.208	0.342	0.136	162.505	
111		0.138	0.342	0.204	314.080	
112		0.149	0.606	0.457	1289.730	

113	2	0.216	0.273	0.057	45.281	
114		0.233	0.262	0.029	18.921	
115		0.144	0.183	0.039	27.423	
116		0.170	0.263	0.093	90.852	
117		0.255	0.295	0.040	28.329	
118		0.224	0.276	0.052	39.991	
119		0.229	0.252	0.023	14.307	
120	13	0.225	0.312	0.087	82.344	
121		0.186	0.470	0.284	552.425	
122		0.208	0.330	0.122	137.118	
123		0.277	0.306	0.029	18.921	
124		0.243	0.320	0.077	68.976	
125		0.286	0.375	0.089	85.140	
126		0.208	0.287	0.079	71.569	
127	3	0.133	0.358	0.225	370.365	
128		0.156	0.321	0.165	221.414	
129		0.141	0.489	0.348	789.821	
130		0.139	0.209	0.070	60.222	
131		0.205	0.318	0.113	121.847	
132		0.261	0.416	0.155	200.127	
133		0.225	0.272	0.047	0.000	Unused
134	4	0.140	0.426	0.286	559.215	
135		0.244	0.261	0.017	10.058	
136		0.227	0.538	0.311	647.512	
137		0.219	0.000	0.000	0.000	Unused
138		0.211	0.250	0.039	27.423	
139		0.181	0.267	0.086	80.962	
140		0.260	0.260	0.000	0.000	Unused
141	17	0.230	0.405	0.175	243.704	
142		0.243	0.329	0.086	80.962	
143		0.223	0.305	0.082	75.534	
144		0.193	0.290	0.097	96.727	
145		0.238	0.313	0.075	66.424	
146		0.186	0.205	0.019	11.434	
147		0.204	0.373	0.169	230.208	
148	9	0.134	0.243	0.109	115.324	
149		0.194	0.368	0.174	241.430	
150		0.236	0.360	0.124	140.623	
151		0.177	0.289	0.112	120.201	
152		0.228	0.330	0.102	104.298	
153		0.218	0.346	0.128	147.755	
154		0.136	0.221	0.085	79.590	
155	10	0.183	0.255	0.072	62.672	
156		0.222	0.328	0.106	110.538	
157		0.250	0.346	0.096	95.243	
158		0.217	0.401	0.184	264.633	
159		0.266	0.370	0.104	107.397	
160		0.249	0.551	0.302	614.995	
161		0.219	0.343	0.124	140.623	
162	5	0.159	0.386	0.227	375.958	
163		0.200	0.265	0.065	54.272	
164		0.208	0.655	0.447	1238.848	
165		0.285	0.285	0.000	0.000	
166		0.247	0.292	0.045	33.011	
167		0.160	0.160	0.000	0.000	Unused
168		0.227	0.227	0.000	0.000	Unused
169	18	0.189	0.331	0.142	173.993	
170		0.215	0.288	0.073	63.913	
171		0.167	0.234	0.067	56.622	
172		0.200	0.287	0.087	82.344	

173		0.142	0.220	0.078	70.267	
174		0.186	0.343	0.157	204.311	
175		0.190	0.683	0.493	1481.299	
176	30	0.214	0.419	0.205	316.659	
177		0.195	0.358	0.163	217.077	
178		0.145	0.398	0.253	452.366	
179		0.213	0.314	0.101	102.763	
180		0.192	0.376	0.184	264.632	
181		0.220	0.606	0.385	946.010	
182		0.260	0.625	0.365	859.860	
183	19	0.164	0.164	0.000	0.000	Unused
184		0.198	0.373	0.175	243.704	
185		0.259	0.368	0.109	115.324	
186		0.265	0.425	0.160	210.649	
187		0.210	0.391	0.181	257.565	
188		0.210	0.454	0.244	425.142	
189		0.181	0.275	0.094	92.306	
190	20	0.224	0.370	0.146	181.855	
191		0.251	0.386	0.135	160.626	
192		0.169	0.215	0.046	33.978	
193		0.167	0.312	0.145	179.874	
194		0.187	0.283	0.096	95.243	
195		0.201	0.310	0.109	115.324	
196		0.228	0.228	0.000	0.000	Unused
197	24	0.182	0.230	0.048	35.942	
198		0.225	0.238	0.013	7.428	
199		0.194	0.256	0.062	50.825	
200		0.220	0.246	0.026	16.569	
201		0.217	0.238	0.021	12.850	
202		0.183	0.202	0.019	11.434	
203		0.181	0.228	0.047	34.954	
204	29	0.210	0.381	0.171	234.666	
205		0.151	0.180	0.029	18.921	
206		0.129	0.214	0.063	51.963	
207		0.162	0.204	0.042	30.171	
208		0.154	0.249	0.095	93.769	
209		0.229	0.408	0.179	252.904	
210		0.252	0.259	0.107	112.123	

APPENDIX IV

Presented below is a copy of the journal provided to the subjects who participated in this study.

Ultraviolet radiation journal

An
Ultraviolet Radiation
Exposure
Journal

Summer 2001

Introduction
As part of a project that I am conducting I will be measuring the amount of UV a child receives when they're outside. Previous studies have shown that overexposure to the sun's UV light may damage human skin. Children who have experienced excessive sunburn are more likely to incur a higher risk of skin cancer during adulthood. A study of this kind has not been undertaken in South Africa before and therefore you all have a very important role to play to make this project a success.

Your role in the project
You are required to wear a badge that will measure the UV you receive in one day for one week. The badge must be pinned to the collar of your shirt (lapel) and is to be worn from the time you wake up until the time you go to bed.

Filling in the UV journal
You need to fill in your daily activities for each day that you wear a badge. It is very important that you do this accurately. You only need to fill in your activities that lasted longer than 5 minutes. You must include all your activities and state whether you were inside or outside when you did them. An example of how to fill in the journal in provided. Please use this as a guide but fill in the activities that **you** do each day. You need to describe the activity, what time you did it, for how long you did it, whether you were inside or outside, what you were wearing and whether you were wearing sunscreen.

Example:
Monday 26th February 2001
Time: 6h45-7h15
Activity: Driving to school in car
Inside/Outside, sun/shade: Inside, shade
Type of clothing: School blazer
Using sunscreen: No

About the badges
1. Please do not touch the film in the centre of the badge. This film is sensitive to UV and your fingerprints will affect the results.
2. Please do not swim or bath with the badge as the cardboard mount will be destroyed. Remove the badge and place it in a dry place still in the sun if you're in the sun, somewhere nearby to where you are and pin it back on once you're dry again.
3. Do not cut the film, apply any type of cream to the film and do not write on the film. Each badge is expensive and should be treated with care.
4. Keep the badge in the brown envelope before you wear it. Do not remove it until the morning that you will wear it. That night when you remove the badge, replace it in the same envelope and seal it.

Thank you for participating in this project. If you have any queries, please contact me:
Caradee Guy
Tel (h): 031 467 7787
Tel (c): 082 677 4037

Day 1: 26 February 2001				
Time	**Type of activity**	**Inside or Outside. If outside, in shade or sun.**	**Type of clothing**	**Using sunscreen**
Day 2: 27 February 2001				
Time	**Type of activity**	**Inside or Outside. If outside, in shade or sun.**	**Type of clothing**	**Using sunscreen**
Day 3: 28 February 2001				
Time	**Type of activity**	**Inside or Outside. If outside, in shade or sun.**	**Type of clothing**	**Using sunscreen**
Day 4: 1 March 2001				
Time	**Type of activity**	**Inside or Outside. If outside, in shade or sun.**	**Type of clothing**	**Using sunscreen**
Day 5: 2 March 2001				
Time	**Type of activity**	**Inside or Outside. If outside, in shade or sun.**	**Type of clothing**	**Using sunscreen**
Day 6: 3 March 2001				
Time	**Type of activity**	**Inside or Outside. If outside, in shade or sun.**	**Type of clothing**	**Using sunscreen**
Day 7: 4 March 2001				
Time	**Type of activity**	**Inside or Outside. If outside, in shade or sun.**	**Type of clothing**	**Using sunscreen**

APPENDIX V

Listed below are the PSFB doses of the mannequin at various anatomic sites.

Table 3. Mannequin PSFB doses data: clear-sky conditions

Anatomic Site	Day 1				Day 2			
	Morning		Afternoon		Morning		Afternoon	
	ΔA_{330}	EUV (J m^{-2})	ΔA_{330}	EUV (J m^{-2})	ΔA_{330}	EUV (J m^{-2})	ΔA_{330}	EUV (J m^{-2})
Control (1)	0.156	202.219	0.184	264.632	0.187	271.791	0.173	2398.165
Control (2)	0.174	241.430	0.173	239.165	0.172	236.911	0.161	212.781
Vertex	0.179	252.904	0.178	250.589	0.209	327.076	0.206	319.248
Forehead	0.112	120.201	0.119	131.936	0.134	158.756	0.125	142.391
Nose	0.121	135.381	0.130	151.381	0.137	164.394	0.121	135.381
Chin	0.103	105.743	0.113	121.847	0.123	138.865	0.116	126.846
Cheek	0.071	61.442	0.062	50.825	0.116	126.846	0.088	83.737
Lapel	0.122	137.118	0.135	160.626	0.163	217.077	0.146	181.855
Shoulder	0.161	212.781	0.169	230.208	0.177	248.284	0.182	259.911
Upper arm	0.128	147.755	0.143	175.944	0.154	198.065	0.148	185.847
Forearm	0.149	187.858	0.158	206.414	0.147	183.846	0.130	151.381
Hand	0.125	142.391	0.059	47.468	0.170	232.432	0.129	149.563
Upper back	0.087	82.344	0.094	92.306	0.110	116.939	0.092	89.401
Lower back	0.042	30.171	0.039	27.423	0.052	39.991	0.052	39.991
Knee	0.109	115.324	0.098	98.221	0.110	116.939	0.097	96.727
Foot	0.119	131.936	0.119	131.936	0.120	133.653	0.108	113.718
Back knee	0.111	118.565	0.126	144.169	0.143	175.944	0.127	145.957
Back calf	0.105	108.962	0.097	96.727	0.105	108.962	0.100	101.239
Front calf	0.098	98.221	0.103	105.843	0.104	107.397	0.094	92.306
Back upper arm	0.086	80.962	0.084	78.227	0.104	107.397	0.102	104.298
Chest	0.151	191.910	0.154	198.065	0.165	221.414	0.153	196.003
Temple	0.091	87.976	0.110	116.939	0.088	83.737	0.094	92.306
Top ear	0.135	160.626	0.110	116.939	0.133	156.898	0.142	173.993
Side ear	0.042	30.171	0.071	61.442	0.071	61.442	0.063	51.964
Back ankle	0.104	107.397	0.099	99.724	0.123	138.865	0.110	116.939
Back elbow	0.053	41.029	0.068	57.812	0.074	65.163	0.075	66.424
Scapular	0.077	68.976	0.079	71.569	0.084	78.227	0.083	76.875
Nape of neck	0.083	76.875	0.078	70.267	0.089	85.140	0.104	107.397

Anatomic Site	Day 3				Day 4			
	Morning		Afternoon		Morning		Afternoon	
	ΔA_{330}	EUV (J m^{-2})	ΔA_{330}	EUV (J m^{-2})	ΔA_{330}	EUV (J m^{-2})	ΔA_{330}	EUV (J m^{-2})
Control (1)	0.187	271.791	0.182	259.911	0.178	250.589	0.182	259.911
Control (2)	0.172	236.911	0.194	288.849	0.177	248.284	0.187	271.791
Vertex	0.184	264.632	0.180	255.230	0.189	276.614	0.194	288.849
Forehead	0.1232	138.865	0.124	140.623	0.125	142.391	0.199	301.338
Nose	0.121	135.381	0.122	137.118	0.122	137.118	0.139	168.203
Chin	0.101	102.763	0.099	99.725	0.117	128.533	0.092	89.409
Cheek	0.117	128.533	0.080	72.880	0.112	120.201	0.067	56.622
Lapel	0.147	183.846	0.139	168.203	0.137	164.394	0.136	162.505
Shoulder	0.152	193.952	0.162	214.924	0.149	187.858	0.173	239.165
Upper arm	0.155	200.137	0.134	158.756	0.131	153.210	0.130	151.381
Forearm	0.164	219.240	0.149	187.858	0.120	133.653	0.153	196.003
Hand	0.154	198.065	0.149	187.858	0.174	241.430	0.166	223.597
Upper back	0.104	107.397	0.098	98.221	0.097	96.727	0.095	93.769
Lower back	0.067	56.622	0.043	31.108	0.036	24.766	0.045	33.011
Knee	0.104	107.397	0.107	112.123	0.3127	145.957	0.104	107.397
Foot	0.128	147.755	0.124	140.623	0.112	120.201	0.125	142.391
Back knee	0.124	140.623	0.121	135.381	0.089	85.140	0.114	123.503

Back calf	0.113	121.847	0.108	113.718	0.111	118.565	0.099	99.725
Front calf	0.105	108.962	0.097	96.727	0.107	112.123	0.106	110.538
Back upper arm	0.057	45.281	0.098	98.221	0.097	96.727	0.093	90.852
Chest	0.165	221.414	0.158	206.434	0.153	196.003	0.168	227.994
Temple	0.120	133.653	0.095	93.769	0.089	85.140	0.110	116.939
Top ear	0.122	137.118	0.125	142.391	0.054	42.077	0.133	156.898
Side ear	0.085	79.590	0.070	60.222	0.087	82.344	0.048	35.942
Back ankle	0.110	116.939	0.104	107.397	0.111	118.565	0.094	92.306
Back elbow	0.100	101.239	0.066	55.442	0.072	62.672	0.069	59.012
Scapular	0.081	74.202	0.094	92.306	0.077	68.976	0.083	76.875
Nape of neck	0.068	57.812	0.073	63.913	0.076	67.695	0.083	76.875

Anatomic Site	**Day 5**			
	Morning		**Afternoon**	
	ΔA_{330}	**EUV (J m^{-2})**	ΔA_{330}	**EUV (J m^{-2})**
Control (1)	0.174	241.430	0.167	225.791
Control (2)	0.167	225.791	0.170	232.432
Vertex	0.178	250.589	0.174	241.430
Forehead	0.127	145.957	0.106	110.538
Nose	0.138	166.294	0.149	187.858
Chin	0.098	98.221	0.110	116.939
Cheek	0.073	63.913	0.084	78.227
Lapel	0.135	160.626	0.133	156.900
Shoulder	0.169	230.208	0.159	208.526
Upper arm	0.131	153.210	0.128	147.755
Forearm	0.160	210.649	0.149	187.858
Hand	0.157	204.311	0.154	198.065
Upper back	0.094	92.306	0.098	98.221
Lower back	0.047	34.954	0.055	43.135
Knee	0.087	82.344	0.094	92.306
Foot	0.109	115.324	0.095	93.769
Back knee	0.119	131.936	0.120	133.653
Back calf	0.116	126.846	0.109	115.324
Front calf	0.098	98.221	0.088	83.737
Back upper arm	0.068	57.812	0.069	59.011
Chest	0.160	210.649	0.152	193.952
Temple	0.094	92.306	0.104	107.397
Top ear	0.069	59.012	0.130	151.381
Side ear	0.056	44.203	0.022	13.573
Back ankle	0.114	123.503	0.092	89.409
Back elbow	0.073	63.913	0.056	44.203
Scapular	0.081	74.202	0.088	83.737
Nape of neck	0.082	75.534	0.072	62.672

Table 4. Mannequin PSFB doses data: overcast-sky conditions

Anatomic Site	**Day 1**		**Day 2**			
	Morning		**Morning**		**Afternoon**	
	ΔA_{330}	**EUV (J m^{-2})**	ΔA_{330}	**EUV (J m^{-2})**	ΔA_{330}	**EUV (J m^{-2})**
Control	0.248	438.651	0.056	44.203	0.115	125.170
Vertex	0.261	477.255	0.057	45.281	0.111	118.565
Forehead	0.148	185.847	0.026	16.569	0.062	50.825
Nose	0.147	183.846	0.033	22.200	0.067	56.622
Chin	0.103	105.843	0.018	10.741	0.045	33.011
Cheek	0.087	82.344	0.012	6.795	0.043	31.108
Lapel	0.187	271.791	0.027	17.343	0.09	86.553
Shoulder	0.222	362.050	0.052	39.991	0.102	104.298
Upper arm	0.154	198.065	0.031	20.541	0.066	55.442
Forearm	0.195	291.327	0.047	34.954	0.081	74.202

Hand	0.230	384.425	0.040	28.329	0.093	90.852
Upper back	0.141	172.053	0.022	13.573	0.056	44.203
Lower back	0.057	45.281	0.005	2.653	0.023	14.307
Knee	0.127	145.957	0.016	9.385	0.062	50.825
Foot	0.143	175.944	0.018	10.741	0.061	49.696
Back knee	0.138	166.294	0.026	16.569	0.083	76.875
Back calf	0.132	155.049	0.022	13.573	0.066	55.442
Front calf	0.121	135.381	0.026	16.569	0.045	33.011
Back upper arm	0.12	133.653	0.023	14.307	0.057	45.281
Chest	0.199	301.338	0.041	29.245	0.084	78.227
Temple	0.104	107.397	0.055	43.135	0.046	33.978
Top ear	0.211	332.345	0.031	20.541	0.084	78.227
Side ear	0.087	82.344	0.012	6.795	0.041	29.245
Back ankle	0.139	168.203	0.006	3.215	0.048	35.942
Back elbow	0.091	87.976	0.006	3.215	0.029	18.921
Scapular	0.093	90.852	0.016	9.385	0.043	31.108
Nape of neck	0.099	99.724	0.008	4.368	0.040	28.329

APPENDIX VI

Included below are the results of the application of a general linear model to the logarithms (base 10) of the subjects' PSFB doses in order to determine significant relationships. Results are discussed in Section 4.8.3.

General linear models procedure

Dependent Variable: LUV

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	49	75.45253780	1.53984771	1.58	0.0204
Error	140	136.50103700	0.97500741		
Corrected Total	189	211.95357480			

R-Square	C.V.	Root MSE	LUV Mean
0.355986	20.55835	0.98742463	4.80303352

Source	DF	Type I SS	Mean Square	F Value	Pr > F
DAY	6	11.56311924	1.92718654	1.98	0.0729
GEN	1	8.02892266	8.02892266	8.23	0.0047
SKIN	2	0.31388764	0.15694382	0.16	0.8515
AGE	2	2.79432124	1.39716062	1.43	0.2421
DAY*GEN	6	5.10046428	0.85007738	0.87	0.5173
DAY*AGE	12	14.15731022	1.17977585	1.21	0.2819
GEN*AGE	2	11.59196014	5.79598007	5.94	0.0033
SKIN*AGE	4	5.81687357	1.45421839	1.49	0.2080
GEN*SKIN	2	0.11838652	0.05919326	0.06	0.9411
DAY*GEN*AGE	12	15.96729229	1.33060769	1.36	0.1898
