




Occupational exposure of workers to solar ultraviolet radiation at selected opencast mining operations in Namibia

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North-West University

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DECLARATION

I, Motsehoa Cynthia Ramotsehoa, hereby declare that the work in this thesis is my own work which is done for the PhD in Occupational Hygiene at the Potchefstroom Campus of the North-West University and has not been previously included in a thesis or dissertation submitted to this or any other institution for a degree, diploma or other qualification.

DEDICATION

The thesis is dedicated to the memory of my late parents, Mme and Ndate, Big Bro Joey, and husband Dr Mankwane 'Papiya' Mokhehle.

In the lyrical words of Paul Hardcastle:

'You may be gone but you will never be forgotten'

MAY YOUR SOULS REST IN ETERNAL PEACE

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ABSTRACT

Title: Occupational exposure of workers to solar ultraviolet radiation at selected opencast mining operations in Namibia.

Introduction: Outdoor workers are exposed to higher solar ultraviolet radiation (UVR) than indoor workers. This puts them at risk of developing negative health effects on the skin and eyes depending on the periods of exposure and skin phototypes. Variations in job activities and associated postures determine the levels of solar UVR exposure in different body positions. Although evidence indicates that winter solar UVR exposure surpasses the International Commission on Non-Ionizing Radiation (ICNIRP) exposure guideline of 1.0 – 1.3 standard erythemal dose (SED) over an 8-hour period, many studies concentrate on solar UVR exposure during summer. The availability, and proper usage of photoprotective measures such as clothing, hats, sunglasses, and sunscreen reduce exposure to solar UVR. The personal exposure of outdoor workers at the selected opencast diamond mining operation in Namibia (22.9576°S, 18.4904°E) has not been quantified.

Aim and objectives: The general aim of the thesis was to quantify the exposure of outdoor workers to personal solar UVR at two opencast diamond mining operations in Namibia. This aim was accomplished by determination of skin colour, the effectiveness of protective clothing, and evaluation of knowledge, attitudes and behaviour related to the risk of exposure to solar UVR of these workers. The aim was achieved through the following specific objectives, i) to quantify the personal exposure of Namibian outdoor opencast mineworkers to solar UVR at different body positions using electronic dosimeters and polysulphone badge dosimeters (PSF) during winter, ii) to establish the constitutive and facultative skin colour of Namibian outdoor opencast mineworkers using a colorimeter, iii) to evaluate the effectiveness of clothing as a protective measure against solar UVR exposure using polysulphone badge dosimeters during winter, and, iv) to evaluate the knowledge, attitudes and behaviour of Namibian outdoor opencast mineworkers related to the risk associated with chronic solar UVR exposure and photoprotection measures using a questionnaire.

Methods: Measurements were conducted at two opencast diamond mining operations in Namibia over four days during winter (site A: 28 June to 4 July 2018, and site B: 6 to 11 July 2018). Outdoor job categories at these opencast mining operations were bedrock, engineering, metallurgy, and security. A total of 38 workers volunteered to participate in the study. The personal exposure of outdoor opencast mineworkers to solar UVR in Namibia was measured using electronic dosimeters based on Schottky Aluminium Gallium Nitride (AlGaN) photodiode worn on the wrist, and PSF badges attached to the hard hat, nape, shoulder, and wrist. Skin colour was measured as individual typology angle (ITA) on the volar upper arm for constitutive skin colour (photoprotected) and dorsal forearm for facultative skin colour (photoexposed) using the Colorimeter CL 400 (Courage + Khazaka Electronics, GmbH, Germany). The PSF badges were placed above and under clothing on the shoulder to assess the effectiveness of clothing as a photoprotective measure. Knowledge, attitudes, and behaviours related to UVR exposure to the sun and the use of photoprotective measures were evaluated using a self-administered questionnaire. Ethical clearance was obtained from the North-West University Health Research Ethics Committee and the Namibia Ministry of Health and Social Services. All ethical requirements were observed through the different activities of this thesis.

Findings and discussion: This thesis reports on findings of measurements from nine electronic dosimeters, 38 PSF badges and ITA, and 36 questionnaires. The mean daily solar UVR exposure measured on the wrist using electronic dosimeters and polysulphone dosimeters was not statistically different. The mean daily solar UVR exposure doses measured using the PSF badges at all body positions (2.07–3.69 SED) and job categories (2.00–3.11 SED), and a total of 89% of the doses measured with the electronic dosimeter (2.60 ± 1.92 SED) exceeded the exposure guideline range of the ICNIRP. The head of outdoor mineworkers in all categories of jobs received the highest levels of exposure. In general, the different body positions received high mean daily percentages of ambient solar UVR with the highest (214.70%) received on the heads of engineering workers. Most of the workers' constitutive skin (photoprotected) was classified into phototypes III to VI (intermediate to black), while facultative (photoexposed) phototypes were classified into phototypes

V (dark brown) and VI (black). This finding aligns with the demographics of Namibia, where 87.0% of the population consists of Black Africans.

Significant differences were found in the ITA of phototypes V (dark brown), and VI (black), pointing to variations within the same phototypes. Also, constitutive (photoprotected) and facultative (photoexposed) phototypes differed significantly. This finding is in line with skin pigmentation that occurs because of adaptation to chronic exposure to solar UVR. Although darker skin phototypes are at a lower risk of skin cancer, they are still susceptible to other pigmentation disorders. Workplace-issued long-sleeved coveralls effectively blocked 97.3% of solar UVR on the shoulder. Higher levels of education were determined to be an indicator of knowledge of the risks of exposure to solar UVR and positive attitudes and behaviours regarding the use of photoprotective measures. A significant proportion of workers had educational levels spanning from no schooling (11%) to various stages of high school education (78%). This was associated with inadequate use of sunscreen (9%) and sunglasses (30%).

Conclusions and recommendations: Outdoor workers at the two opencast diamond mining operations in Namibia are at risk of overexposure to solar UVR and the related negative health effects during winter regardless of skin colour and job category. Future solar UVR exposure studies should be conducted over longer periods to include larger sample sizes, different seasons, and other dosimeters to compensate for the failure of some electronic dosimeters experienced in this thesis. Photoprotection should be improved by supplementing the workplace-issued coveralls with photoprotective measures for the neck, eyes, and exposed skin. Poor use of sunscreen and sunglasses should be addressed through the implementation of training and education programmes, and follow-up assessments to determine the effectiveness of such programmes. Consideration should be given to different phototypes, workplace contexts, and education levels during the design and implementation of such intervention programmes. Limitations of this thesis are acknowledged.

Key words: outdoor work, photoprotection, phototypes, dosimeters, occupational exposure, sun safety training.

PREFACE

This thesis is compiled in article format and is written to conform with the requirements of the North-West University 's Manual for Higher Degrees and author guidelines of the appropriate journals. The thesis is written according to United Kingdom English spelling, except for institutional names and references that were used as is.

The following three articles form part of this thesis:

- Article I (Chapter 3): Solar ultraviolet radiation exposure among opencast miners in Namibia with the use of electronic dosimeters: a feasibility study.
- Article II (Chapter 4): Solar ultraviolet radiation exposure of mineworkers at selected opencast mining operations in Namibia.
- Article III (Chapter 5): Solar ultraviolet radiation-related knowledge, attitudes, and behaviours of opencast mineworkers in Namibia.

The reference style of the journal, *Annals of Work Exposures and Health*, given as Supplement A at the end of Chapter 6, is used in all chapters with the exception of Chapter 3.

Chapter 3 follows the author guidelines for the journal, *Annals of Global Health* that are presented at the beginning of Chapter 3.

The contributions of the listed co-authors and their consent for use in this thesis are given in Table 1.








THESIS OUTLINE

The outline of the thesis is as follows:

- Chapter 1 - General introduction with background research aims and objectives, and hypotheses.
- Chapter 2 - A literature study on topics relevant to this thesis.
- Chapter 3 - Article I: Solar ultraviolet radiation exposure among opencast miners in Namibia with the use of electronic dosimeters: a feasibility study.
- Chapter 4 - Article II: Solar ultraviolet radiation exposure of mineworkers at selected opencast mining operations in Namibia.
- Chapter 5 - Article III: Solar ultraviolet radiation-related knowledge, attitudes, and behaviours of opencast mineworkers in Namibia Chapter 3.
- Chapter 6 - A summary of the main findings of the study is provided and conclusions are drawn. Additionally, recommendations are made and the limitations of the study as well as recommendations for future studies are provided.
- Supplement A: Author instructions for annals of workers exposure and health.
- Supplement B: Questionnaire.
- Supplement C: Ethics approval certificates.
- Supplement D: Informed consent form
- Supplement E: Declaration of language editing.
- Supplement F: Turn-It-In summary report.

AUTHORS' CONTRIBUTIONS

Table 1. Author contributions to the thesis and consent of use

Author	Contribution	Consent*
Ms MC Ramotsehoa	The conception and design of the study under the supervision of the promoters, ethics application, data collection, funding application, analysis & interpretation of data, writing of manuscripts (articles) and the thesis.	
Prof FC Eloff	As promoter, made substantial contributions to the conception and design of the study, ethics application, funding application, data collection, review and final approval for the submission of the thesis	
Prof J.L du Plessis	As co-promoter made substantial contributions to the conception and design of the study, funding application, ethics approval and amendments, ensuring data integrity, Final approval of the thesis and the articles that form part of the thesis	
Prof CY Wright	As assistant promoter, made substantial contributions to the conception and design of the, contributions to the analysis, and interpretation approval of the manuscripts and the thesis.	
Dr DJ du Preez	Contributed to the analysis and interpretation of data, made inputs and final approval of the manuscripts (article) in Chapter 3.	
Dr T. Kapwata	Carried out analysis and interpretation of data, made significant inputs into the presentation of the manuscript (article) in Chapter 5	
Dr Karlien Linde	Contributed to data analysis verifications, inputs and final approval of manuscript (article) in Chapter 4	

*I declare that I have approved the chapter/article(s) and that my role in the study as indicated above is representative of my actual contribution, and that I hereby give my consent that it may be published as part of the PhD thesis of Ms MC Ramotsehoa.

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LIST OF ABBREVIATIONS

ITA	individual typology angle
CIE	International Commission on Illumination
IARC	International Agency for Research on Cancer
ICNIRP	International Committee on Non-Ionizing Radiation Protection
ILO	International Labor Organization
MED	minimal erythematol dose
%	percentage
PSF	polysulphone dosimeter
SED	standard erythematol dose
UPF	ultraviolet protection factor
UVR	ultraviolet radiation
WHO	World Health Organization

LIST OF UNITS

J/m^2 Joules per metre squared

μ micrometre

nm nanometre

W/m^2 Watt per metre squared

TERMINOLOGY

The neck and nape are used interchangeably in this thesis.

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CHAPTER 1: GENERAL INTRODUCTION

1.1 Background and problem statement

Namibia (22.9576°S, 18.4904°E) is located north-west of South Africa, with the Orange River serving as a landmark separating the two countries, while it also shares borders with Angola, Botswana, and Zambia (South African History Online, 2023; World Bank, 2023). Although it is the driest country in sub-Saharan Africa, Namibia has an abundance of mineral resources that include uranium, diamonds, gold, iron ore, manganese, silver, and zinc, among others (World Bank, 2023). In 2023, the Namibian mining sector employed approximately 18 189 people and contributed 14.4% to the gross domestic product (Chamber of Mines of Namibia, 2023). Depending on the mineral or metal, Namibia uses opencast (open pit), underground, offshore, and onshore mining (Crawford *et al.*, 2018). Opencast mining is used when ore deposits are located closer to the surface (Altitit *et al.*, 2021). This thesis focuses on outdoor workers employed at two opencast diamond mining operations in Namibia.

Outdoor workers are workers who receive regular and significantly higher exposure to solar ultraviolet radiation (UVR) than indoor workers (Gies and Wright, 2003). This high exposure is mostly due to the inability to schedule work activities outside of the peak hours for solar UVR exposure dose, i.e., 10h00-14h00 when the intensity of the sun is at its highest (Glanz *et al.*, 2007; Łastowicka-Moras *et al.*, 2014). More recently, Wittlich, (2022) defined outdoor workers as those who spend 22% of their working time outdoors. This is significant for Namibia since the proportion of individuals occupationally exposed to solar UVR in Namibia stood at an estimated 26.86% (95% uncertainty range of 22.72–31.00%) in 2019 (Pega *et al.*, 2023).

Solar UVR has both beneficial and negative health effects depending on the amount and period of exposure (Tang *et al.*, 2024). The benefits of exposure to solar UVR include the production of vitamin D, which is essential for the maintenance of good bone, muscular health, immune function, and the regulation of several metabolic pathways (Agoncillo *et al.*, 2023; Passeri and Giannini, 2023). The negative health effects linked to solar UVR

exposure include cutaneous malignant melanoma (Elder *et al.*, 2020) and keratinocyte cancer (KC) also known as non-melanoma skin cancers (NMSC) namely, basal cell carcinoma (BCC) and squamous cell carcinoma (SCC) (Leiter *et al.*, 2020). Intermittent and long-term exposure to solar UVR increases outdoor workers' susceptibility to the development of KC (Loney *et al.*, 2021). Other negative health effects include photokeratitis and photoconjunctivitis that occur due to acute solar UVR exposure of the eyes, while chronic exposure to the eye causes SCC of the conjunctiva and cortical cataracts (Mofidi *et al.*, 2018; Schmalweiser *et al.*, 2021). Based on 2019 data, it is estimated that eliminating solar UVR exposure for the Namibian population would result in a 34.12% reduction (with a 95% uncertainty interval ranging from 26.23% to 43.51%) in the average risk of NMSC over a particular period, provided that other conditions stay constant (Pega *et al.*, 2023).

Differences in genetic attributes such as skin colour (phototype) determine an individual's response to solar UVR exposure and the extent of both positive and negative health effects (Maddodi *et al.*, 2012; Modenese *et al.*, 2019). Natural skin phototype is determined by the amount and types of melanin in the skin that are distinctive of constitutive skin phototypes on photoprotected skin (Jablonski and Chaplin, 2010). Changes in melanin concentration between photoprotected (constitutive) and photoexposed (facultative) phototypes happen as a physiological response to extended solar UVR exposure (Del Bino and Bernerd, 2013; Yardman-Frank and Fisher, 2021). Darker skin phototypes have higher melanin content which affords the skin better protection against solar UVR than the lighter skin phototypes (Gupta *et al.*, 2016; Munjal and Ferguson, 2023). However, skin damage does occur in darker skin phototypes when solar UVR exposure levels are high (Fajuyigbe and Young, 2016). Black Africans make up 87% of the Namibian population (Namibia Statistics Agency, 2024).

Subjective skin phototyping was developed by Fitzpatrick (Fitzpatrick, 1988) using the skin's likelihood to burn or tan upon exposure to solar UVR as a base. The Fitzpatrick skin phototyping system was originally designed for lighter skin types, making questions about sunburn, an unfamiliar notion for those with darker skin, it is ineffective in accurately

classifying the darker skin phototypes (Lim *et al.*, 2023). Furthermore, darker skin types exhibit diversity and can vary even within the same ethnic groups (Green, 2023). Thus, objective classification using instruments such as colorimeters is more dependable in establishing skin colour (Eilers *et al.*, 2013). The constitutive skin colour and associated changes caused by occupational solar UVR exposure have not been evaluated in outdoor opencast mineworkers in Namibia. The establishment of the workers' skin colour using objective measurements will bring about understanding of effects of solar UVR exposure on the workers' skin.

Differences in work activities and related postures were identified in occupations such as farming and construction. These determine the body positions that are at higher risk of solar UVR exposure based on their orientation towards the sun (Gies and Wright, 2003; Lucas *et al.*, 2008; Schmalweiser *et al.*, 2010; Vernez *et al.*, 2015). Also, significant differences were observed in exposure even within the same job categories (Merin *et al.*, 2023). The absence of data regarding exposure levels on various body positions among Namibian outdoor opencast mineworkers restricts understanding of how photoprotection strategies should be focused.

The objective of photoprotective measures is to reduce exposure to solar UVR. These measures include avoidance of exposure during peak periods, clothing, sunscreens, wide-brimmed hats, and sunglasses (Tsai and Chen, 2022; Gabros *et al.*, 2024). Considering that avoidance of peak period exposure is not always possible in outdoor occupations (Łastowicka-Moras *et al.*, 2014), focus is often placed on personal protection. Clothing made of thicker fabric and darker colour offer greater effectiveness in protecting the skin against solar UVR (Bielinski and Bielinski, 2014). Also, consistent application of sunscreen decreased the incidence of melanoma (Green *et al.*, 2011), while sunglasses or UV protective goggles protect the eyes from negative effects of solar UVR exposure (Görig *et al.*, 2024). The use of personal protective equipment often faces compliance difficulties (Zink *et al.*, 2017; Görig *et al.*, 2020) and warrants investigation in opencast mining operations. Peters *et al.* (2016) found that employees working in environments with sun safety policies exhibited better photoprotective behaviours. They identified lighter

skin types and older age as predictors of such behaviours. Additionally, Agarwal *et al.* (2018) noted that workers with higher educational levels possessed a strong understanding of the dangers of solar UVR exposure and exhibited positive attitudes and behaviours regarding photoprotective measures. The relationship between workplace factors and personal attributes in the use of photoprotective measures has not been established in the selected opencast mining operations.

Implementation of preventive measures is currently insufficient, largely due to the absence of legislation to mitigate against occupational exposure to solar UVR (Lucas *et al.*, 2016; Modenese *et al.*, 2018; Wright and Norval, 2021; Cherrie and Cherrie, 2022). Consequently, employers lack clarity on the most effective ways to manage solar UVR exposure without specific legislation or regulations enforcing measures, in Africa (Lucas *et al.*, 2016; Wright and Norval, 2021), and Namibia specifically (Ministry of Labour, 2007). As a result, the International Labor Organization (ILO) (2018) advocated for regulations to encompass solar UVR as a workplace hazard specifically in opencast mining operations. For many years, the ICNIRP recommended a range of 1.0 to 1.3 standard erythemal dose (SED), based on the International Commission on Illumination (CIE) action spectrum as an exposure guideline over an 8-hour period (CEN, 2008; ICNIRP, 2010). SED is a standardised measure of erythemogenic UV radiation which can be used for all skin phototypes (where 1 SED is equivalent to an erythemally effective radiant exposure of 100 J/m²) (CIE 125, 1997).

Varying exposure patterns were identified in different studies that pointed to exposures above the ICNIRP exposure guideline. For example, construction workers in Romania and Britain were exposed to 1.28 to 6.5 SED per day during summer on the wrist and a daily mean of 2.0 SED on the back of the head respectively (Moldovan *et al.*, 2020; Cherrie *et al.*, 2021). South African farmworkers on the other hand received average solar UVR doses of 7.7 to 13.9 SED on the head between autumn and summer (Linde *et al.*, 2022). Solar UVR exposure of Australian outdoor workers was 0.91 SED (chest and shoulder) (Neale *et al.*, 2010), while New Zealand construction, physical education teachers and farmers received between 0 and 21 SED on the chest and wrist during

winter (Gies *et al.*, 2014). Personal exposure and exposure as a percentage of ambient UVR were found to be higher in winter than summer respectively (Downs *et al.*, 2014; Neale *et al.*, 2010). Also, approximately 42% of the total annual exposure is received in winter (Neale *et al.*, 2010). The lack of solar UVR exposure data in the opencast mining industry contributes to the lack of knowledge about exposure patterns particularly because winter is excluded in most studies (Lucas *et al.*, 2016; Nkogotse *et al.*, 2019; Peters *et al.*, 2020; Cherrie *et al.*, 2021; Linde *et al.*, 2022).

Solar UVR exposure measurements play a key role in linking ambient solar UVR levels and health effects while it also serves as a guide for selection of appropriate protective measures (Kezic and van der Molen, 2023). Workers who are a risk of high exposure to solar UVR are also identified through exposure data (Kovačić *et al.*, 2020). Thus, measurements with personal dosimetry are necessary (Thieden *et al.*, 2000; ICNIRP, 2010; Kezic and van der Molen, 2023) and served as motivation for this thesis because of the lack of knowledge of solar UVR exposure of outdoor opencast mineworkers in Namibia.

Electronic dosimeters and polysulphone badge dosimeters are two examples of personal dosimeters that were used in this study. More specifically, Aluminium Gallium Nitride (AlGaN) photodiode based electronic dosimeters were sourced from Electrical and Computer Engineering Department, University of Canterbury, Canterbury, New Zealand. These dosimeters allow for sampling intervals from 8 to 60 seconds, thereby providing time-stamped data throughout the shift (Allen *et al.*, 2020). Electronic dosimeters can be attached to clothing or worn on the wrist using a wrist strap (Allen and McKenzie, 2005). Polysulphone dosimeter badges are manufactured at the University of Manchester, United Kingdom using a plastic film that is mounted on a cardboard casing. The plastic film undergoes photodegradation observed as change in absorbance upon exposure to solar UVR. Unlike electronic dosimeters, polysulphone dosimeter badge provide total daily exposure (Geiss *et al.*, 2003). Both dosimeters are placed next to a broadband radiometer that measures biologically effective irradiance for calibration with minor differences in the actual methods.

1.2 Aim and objectives

The aim of this thesis was to quantify personal solar UVR exposure of outdoor workers at two opencast diamond mining operations in Namibia with consideration of skin colour and effectiveness of protective clothing. The knowledge, attitudes and behaviour related to the risk of exposure to solar UVR of these workers were also evaluated.

1.2.1 Study objectives

The general aim of this thesis was achieved through the following specific objectives:

- i. To quantify personal exposure of Namibian outdoor opencast mineworkers to solar UVR on different body positions using electronic dosimeters and polysulphone badge dosimeters during winter.
- ii. To establish the constitutive (photoprotected) and facultative (photoexposed) skin colour of Namibian outdoor opencast mineworkers using a colorimeter.
- iii. To evaluate the effectiveness of clothing as a protective measure against solar UVR exposure using polysulphone badge dosimeters during winter.
- iv. To evaluate the Namibian outdoor opencast mineworkers' knowledge, attitudes, and behaviours related to the risk associated with chronic solar UVR exposure and photoprotection measures by making use of a questionnaire.

1.3 Research hypotheses

1.3.1 Hypothesis 1

According to Neale *et al.* (2010), although the ambient solar UVR is three times higher in summer than in winter, the exposure as a percentage of ambient solar UVR is two times higher in winter. Studies in which winter was either the focus or was included in seasonal solar UVR exposure, indicated that the winter dose was not only higher than the summer dose (Downs *et al.*, 2019), but it also exceeded ICNIRP exposure guideline (Kimlin *et al.*, 2006; Gies *et al.*, 2014). Therefore, it is hypothesised that the solar UVR exposure of Namibian outdoor opencast mineworkers to solar UVR on different body positions during winter exceeds the ICNIRP exposure guideline of 1.0 to 1.3 SED over an 8-hour period.

1.3.2 Hypothesis 2

Skin pigmentation also known as tanning, is a physiological response to solar UVR exposure. With chronic exposure, differences are observed between constitutive skin colour on photoprotected and facultative skin colour on photoexposed areas (Tadokoro *et al.*, 2005; Naik and Farrukh, 2022). It is therefore hypothesised that the ITA of constitutive (photoprotected) skin differs significantly from that of facultative (photoexposed) skin of Namibian outdoor opencast mineworkers.

1.3.3 Hypothesis 3

Of all measures available to the outdoor worker against solar UVR exposure, clothing is an important form of protection (ICNIRP, 2010). The mining operation distributes safety coveralls intended to shield workers from various weather conditions (Mining Safety, 2021). In terms of protective efficiency, thicker fabrics like denim offer superior UVR protection (Ghazi *et al.*, 2010). It is therefore hypothesised that the type of clothing issued and worn by Namibian outdoor opencast mineworkers effectively reduce UVR transmittance of solar UVR.

1.3.4 Hypothesis 4

Employers are obliged to train employees in the type of hazard they are likely to be exposed to, the health effects of such exposure as well as on the methods they may use to either reduce their own exposure or protect themselves (ILO, 2018). However, evidence showed that outdoor workers generally lack knowledge about their health, which therefore contributes to their risky behaviour and the resultant elevated risk for skin cancer (John *et al.*, 2016; Nkogatse *et al.*, 2019). Thus, it is hypothesised that the Namibian outdoor opencast mineworkers lack knowledge about the hazards and appropriate protection measures related to solar UVR exposure.

1.4 Reference list

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CHAPTER 2: LITERATURE STUDY

Occupational exposure to solar UVR is one of the most important aspects of the health and well-being of outdoor workers (Slavinsky *et al.*, 2024). Therefore, this literature study reflects on the different aspects related to solar UVR and the identification of unanswered questions in related literature. It is important to set out the context of the literature review by summarising the literature on solar UVR as an environmental factor, factors influencing personal exposure, health effects, occupational exposure legislation, and control measures. This literature study concludes with findings of solar UVR exposure studies showing some conflicting findings and shortcomings.

2.1 Background on solar UVR

Ultraviolet radiation (UVR), visible light, and infrared radiation are part of optical radiation within the electromagnetic spectrum (Gallagher *et al.*, 2006). UVR is an invisible part of optical radiation with wavelengths shorter than visible light (Cherrie and Cherrie, 2022). The sun is the main source of UVR on Earth, whereas industrial and some recreational instruments and processes represent artificial sources of UVR. UVR is divided into UVA (315-400 nm), UVB (280-315 nm), and UVC (100-280 nm) radiation (Passeron *et al.*, 2021) with UVA and UVB classified into narrow bands: UVB (280–315 nm), UVA2 (320–340 nm), and UVA1 (340–400 nm) (Ahmad *et al.*, 2017). Approximately 94% of UVA and 6% of UVB reach the Earth's surface (United States Environmental Protection Agency (US EPA), 2023). Although it makes out a small percentage of solar UVR that reaches the Earth's surface, UVB is responsible for acute and chronic health effects on the skin and eyes (Modenese *et al.*, 2016). Regarding the impact on the skin, UVB penetration is limited to the basal layer of the epidermis while UVA penetrates deeper into the dermis (Holick, 2016; Tang *et al.*, 2024). UVA stimulates the production of reactive oxygen species, which in turn leads to DNA damage such as single-strand DNA breaks, crosslinks and altered bases. DNA also acts as an actual chromophore for UVB and as such, direct absorption causes the formation of cyclobutane–pyrimidine dimers and 6–4 pyrimidine–pyrimidone photoproduct lesions (Pfeifer and Besaratinia, 2012; Marteiijn *et al.*, 2014; Martens *et al.*, 2018; Mullenders, 2018; Pfeifer, 2020). DNA lesions lead to a halt in DNA synthesis creating a significant challenge for the cell as it must replicate the damaged

DNA before mitosis to ensure that both daughter cells receive a complete copy of the genome (Sale *et al.*, 2012).

UVC on the other hand, does not reach the Earth's surface due to the absorption by the ozone and blockage through scattering by particulates and clouds of all wavelengths shorter than 290 nm. With UVC inherently containing more energy and mutagenic properties, it would have had significant effects on all living organisms had it not been for the complete absorption by the atmosphere (Svobodova *et al.*, 2006). These characteristics of UVC became useful in the decontamination of surfaces in clinical settings with UVC lamps during the COVID-19 pandemic (Gupta *et al.*, 2021), although other studies reported it to be ineffective against this virus (Alnaser *et al.*, 2020).

2.2 Environmental factors influencing exposure to solar UVR

The amount of solar UVR that reaches the Earth's surface is the main determinant of the amount of solar UVR to which an outdoor worker is exposed. Latitude and altitude, albedo, solar zenith angle, cloud cover, seasons, and climate change are among the environmental factors that affect the exposure of outdoor workers to solar UVR (Jahdi and Arab, 2022).

2.2.1 Latitude and altitude

In basic terms, latitude is a measure of a site's location either north or south of the equator, while altitude is the measure of height above sea level (Britannica, 2023). The poles experience relatively higher levels of UVA because the latitudinal bands that distribute UVA are wider compared to those of UVB. When at higher altitudes, the atmosphere is thinner and less capable of absorbing solar UVR, which leads to notable differences in UVB and UVA (Grigalavicius *et al.*, 2016). For instance, an altitude increase of 1000 m leads to a rise of 10% to 12% in solar UVR (WHO, 2002). Studies indicate that UVB radiation elicit a reduced immune response that intensifies as one moves closer to the equator, while UVA is responsible for about 57% of the sun-induced immunosuppression at noon on the equator (Grigalavicius *et al.*, 2016). Africa, being under the influence of latitude, generally experiences higher and more consistent levels of UVB compared to

Northern Eurasia (Jablonski and Chaplin, 2010). This increased UV level is an aspect that affects the exposure dose of solar UVR experienced by Namibian opencast miners.

2.2.2 Albedo

According to Coakley (2003), albedo is defined as the portion of incident sunlight that is reflected by a surface. Albedo differs from one surface to another with grass having a much lower reflectance, followed by water, then concrete and snow (Behar-Cohen, 2014). Bricks in surrounding buildings also have a lower reflectivity effect (Weihs *et al.*, 2013). Albedo of the ground with a lighter colour, such as snow-covered ground, adds to the increase in UVA levels (Coakley, 2003). Although albedo is acknowledged as a factor in the total solar UVR dose received by an exposed individual, it is rarely measured in exposure studies. The lower reflectivity of most surfaces found around outdoor workspaces may have contributed to a lack of reflectance measurements (Turner and Parisi, 2018). However, it is important to note that the albedo of a surface, instead of being a constant, changes depending on the spectral and angular distribution of the incident light that is in turn determined by the composition of the atmosphere and the direction of the beam of light originating from the sun. Also, surfaces are a combination of different elements that may not have uniform reflectance properties (Coakley, 2003). Thus, albedo is a somewhat complex but equally important factor to consider in exposure measurement studies. This is made possible using a combination of broadband radiometers and pyranometers. However, the strengths and limitations of each one must be considered. Coakley (2003) elaborated on these characteristics.

2.2.3 Solar zenith angle

The solar zenith angle (SZA) is described as the angle of elevation of the sun above the horizon. It is determined by the time of day, season, and latitude (Young, 2006; Kerr and Fioletov, 2008; ICNIRP, 2010). The amount of solar UVR measured on a horizontal surface decrease as SZA increases. This phenomenon occurs because the surface irradiance is proportional to the cosine of the SZA, and as the radiation travels through the atmosphere, the path length increases, which increases the SZA (Kerr and Fioletov, 2008). In winter, the large SZA implies that the path travelled by solar UVR through the

atmosphere is longer, with a resultant spread of energy over a much larger surface area (Webb, 2006). With the exposure measurements carried out in winter in this thesis, SZA is an important aspect to bear in mind.

2.2.4 Seasons

A substantial percentage of the annual UVR exposure dose is received in winter (McKenzie and Lucas, 2018; Dobbinson *et al.*, 2008). However, the focus of solar UVR exposure measurement studies is generally on warmer seasons with the exclusion of winter (Linde *et al.*, 2021). This is an important aspect to seasonal exposure since messages about protection are usually linked to summer exposure with the exclusion of winter (Neale *et al.*, 2010). However, exposure as a percentage of the ambient solar UVR is likely to be higher in winter than in summer. Numerous factors might explain the observed variation in the percentage of ambient UVR received during summer and winter. The effectiveness of shade structures in providing protection is reduced in winter because of the high solar zenith angle (Turnbull and Parisi, 2004). However, behavioural changes are probably the main reason. In contrast to summer, people might spend more time outside in winter, be outdoors at different times of the day, or be less inclined to find shade when outside (Neale *et al.*, 2010). Also, more time is spent outdoors in winter, SZA is higher, and people are less likely to seek shade in winter (Neale *et al.*, 2010; Sun *et al.*, 2014). Thus, studies on management of exposure throughout the year in countries where winter temperatures are mild, allowing outdoor activities, are required (Dobbinson *et al.*, 2008). Namibia is one such country. A comparison of previous studies represented in Table 2 (Section 2.6.4) shows some of these conflicting findings in solar UVR exposure measurements.

2.2.5 Cloud cover

As solar UVR passes through the clouds, which are by their nature made up of ice crystals and/or small water molecules, the intensity of solar radiation is reduced. Overall, clouds have an attenuation effect that is dependent on time and space as well as cloud characteristics such as amount, optical thickness, type, and layers (Calbó *et al.*, 2005).

The scattering of solar UVR caused by surface albedo reduces the optical depth of clouds and, in turn, increases UV intensity (Behar-Cohen, 2014).

2.2.6 Climate change

Short term changes in climate, result in minor changes in temperature, humidity, rainfall, and soil moisture (Haines *et al.*, 2006). Additionally, forecasts for Africa point to increases in extreme temperatures, such as heat waves, and related harmful effects on health due to climate change (Rother *et al.*, 2020). The clothing workers wear for protection against other occupational hazards, limits the body's ability to cool down, thereby increasing their risk of suffering from heat stress or stroke and higher mortality (Moda *et al.*, 2019). Outdoor occupations by their nature, expose workers to these extreme weather conditions because of the types of activities that must be performed outdoors (Schulte and Chun, 2009). The intensification of UVB rays due to climate change will increasingly present more significant challenges (Wright *et al.*, 2019). Rising levels of ambient solar UVR are expected to lead to a higher incidence of skin cancer, which is associated with temperature increases, although the exact mechanism is not entirely clear (Lucas *et al.*, 2019; Bernhard *et al.*, 2023). An increase of 5.5% in squamous cell carcinoma (SCC) and 2.9% in basal cell carcinoma (BCC) incidences respectively for every 1°C increase in temperature were reported (van der Leun *et al.*, 2008; Parker, 2021).

There is an observed recovery of the ozone layer due to the implementation of the Montreal Protocol (Kuttippurath and Nair, 2017). However, reductions in UVB radiation at the Earth's surface due to the recovery of stratospheric ozone have not been observed yet because these changes are still obscured by the fluctuating reduction of UVR by ozone, clouds, aerosols, and other factors (Bais *et al.*, 2018). Therefore, there is a need for studies to determine the impact of climate change on workplaces and the development of mitigative measures (Moda *et al.*, 2019; Rother *et al.*, 2020).

2.3 Personal factors that influence exposure to solar UVR

The measurements of exposure to solar UVR have demonstrated wide variations in the dose received by workers. Factors that play an important role in addition to environmental

factors, are personal characteristics such as skin type, gender, posture adopted while performing work activities, and knowledge, attitudes and behaviour or practices (Modenese *et al.*, 2019).

2.3.1 The skin

To understand the response to solar UVR and its impact on the skin, it is fitting to discuss the biological characteristics of the skin in terms of melanin and the role it plays in pigmentation and photoprotection (Norval, 2001).

2.3.2 Skin colour

To classify skin colour according to phototypes, the Fitzpatrick skin phototype classification system (Table 1) is widely used. The system is based on self-reporting of race and pigmentation and gives some indication of sensitivity to solar UVR. The system however has limitations such as, not being a strong predictor of sunburn (Del Bino and Bernerd, 2013; He *et al.*, 2014), and that black Africans do not identify with the concept of sunburn (Pichon *et al.*, 2010; Del Bino and Bernerd, 2013; Wright *et al.*, 2015). For example, a South African study revealed that black African farmers subjectively classified their skin as lighter than was determined with objective measurements (Linde *et al.*, 2020). Furthermore, skin phototypes vary within the same ethnic or racial groups (Goldenberg *et al.*, 2015).

Table 1. Fitzpatrick skin-colour classification system as adapted from Fitzpatrick (1988) by Wright *et al.* (2013).

Skin phototypes	History of sunburn	Individual typology angle
I. Very Light/ Very White	Always burns	>55
II. Light/White	Usually burns	>41 <55
III. Intermediate/ White to Olive	Sometimes burns	>28 <41
IV. Tan	Rarely burns	>10 <28
V. Brown	Very rarely burns	<10 >-30
VI. Dark brown/Black	Never burns	≤-30

Studies have indicated that objective colorimetric/spectrophotometric methods used to measure pigmentation and melanin are more precise, safer and faster options for skin

type evaluations that can be linked to clinical characteristics (Wilkes *et al.*, 2015). The bioengineering instrument used in this study is the Colorimeter® CL400 (Courage Khazaka, Germany).

2.3.3 Melanin and the role it plays in pigmentation and photoprotection

The natural pigment of an individual's skin is known as constitutive pigmentation, which, due to tanning on photoexposed skin areas, changes into facultative pigmentation (Jablonski and Chaplin, 2010). Constitutive pigmentation determines how the skin is affected by damage, wrinkle formation, thickening, degeneration of elastic fibres, and loss of elasticity in the connective tissue of the skin (Del Bino and Bernerd, 2013)

Pigmentation is determined by melanins which are pigments of varying structures and origins that are formed through the oxidation and polymerisation of tyrosine (d'Ischia *et al.*, 2013). Melanins are synthesised in specialised cells named melanocytes, primarily located at the junction between the epidermis and dermis (Ando *et al.*, 2012). Melanins are stored in specialised organelles called melanosomes which are approximately 500 nm in diameter (Bastonini *et al.*, 2016). They are moved from melanocytes to neighbouring keratinocytes as melanin granules that are usually less than 1 µm in diameter (Michalak-Mińska *et al.*, 2022). There are two types of melanins namely, pheomelanin and eumelanins. Eumelanins are black-to-brown soluble pigments that are partially created through the oxidative polymerisation of L-3,4-dihydroxyphenylalanine(L-dopa) by 5,6-dihydroxyindole intermediates. Pheomelanins are yellow-to-reddish brown, alkali-soluble, and sulphur contain pigments that results from the oxidation of cysteinyl-dopa precursors through benzothiazine and benzothiazole intermediates (d'Ischia *et al.*, 2013).

The ratio of eumelanin to pheomelanin affects skin pigmentation. Variations in the size, quantity, and arrangement of melanosomes, along with the type of melanin produced and the melanin concentration in melanosomes, which can vary from 17.9 to 72.3%, determine skin pigmentation (Brenner and Hearing, 2008; Del Bino and Bernerd, 2013). Therefore, individuals with lighter skin have a higher concentration of the light, alkali-

soluble pheomelanin, whereas those with darker skin have a greater amount of eumelanin. The eumelanin pigment has a higher efficiency at blocking UV photons by converting radiation into heat, preventing damage from harmful radical reactions, while also possessing antioxidant and free radical neutralizing properties. (Ilina *et al.*, 2022; Terranova, 2023). In contrast, pheomelanin has been identified as a significant factor in the increased risk of solar UVR damage, and skin cancer in individuals with lighter skin phototypes due to its ability to sensitise to light, resulting in the generation of elevated levels of reactive oxygen species (Mitra *et al.*, 2012).

2.3.4 Gender

In a study of French outdoor workers, men received higher exposure than women, although this was dependent on the type of job (Boniol *et al.*, 2015). In contrast, no significant differences in the solar UVR exposure of men and women outdoor workers were reported in a Danish study (Borup *et al.*, 2020). In particular, it was discovered that immunosuppression in males occurred at solar UVR levels that were one-third of those required for women (KüttingKütting and Drexler, 2010). A study of farmers in Austria found a 5.5 times higher risk of developing keratinocyte cancer (KC) (also known as non-melanoma skin cancer) in females when compared to men, based on facial solar UVR exposure measurements. The type of head protection, hats and caps for male farmers and head scarves for female farmers, contributed to these observed differences (Schamalwieser *et al.*, 2010). Also, even though they applied sunscreen more often (Thieden *et al.*, 2005; Lewis *et al.*, 2006) significantly more risk-behaviour days without sunscreen applied was observed in women than men in a Danish study (Thieden *et al.*, 2005). The wearing of hats was found to be the same for men and women in another study conducted in the United States of America (Lewis *et al.*, 2006).

2.3.5 Posture or body orientation to the sun

There are inherent differences in work activities and related postures between work environments such as farming and construction, to name a few of the occupations that have been extensively studied (Gies and Wright, 2003; Lucas *et al.*, 2008; Vernez *et al.*, 2015). Outdoor workers generally receive higher solar UVR doses in areas of the upper

body such as the head, neck, and shoulder (Vernez *et al.*, 2015; McKenzie and Lucas, 2018). Differences in the distribution of solar UVR dose on the different body positions were observed in fishermen based on the type of fishing activity they performed (Modenese *et al.*, 2019). The patterns of solar UVR distribution over a human body are determined by environmental factors such as SZA, atmospheric composition and ground albedo (Jahdi and Arabi, 2022) that are described in section 2.2 of this chapter. In the long term, the dose received at specific body positions will lead to chronic overexposures (Milon *et al.*, 2007). However, workers engaged in the same activities at the same workplace, are likely to have different solar UVR exposure patterns due to differences in the postures they assume (Kimlin *et al.*, 2006). This in turn determines the orientation of the body positions towards the sun and the resultant dose received (Weihs *et al.*, 2013) and should be featured in photoprotection awareness campaigns (Milon *et al.*, 2007).

Workers who performed activities in a seated position were found to be at a higher risk of developing negative health effects on the anterior thigh and shin compared to those who assumed a standing position. Therefore, photoprotection of the lower body positions should be recommended for wheelchair-bound workers. Also, this factor highlights the importance of the inclusion of anatomical positions other than upper body positions in the solar UVR exposure measurement (Parisi *et al.*, 2003). With the lack of workplace solar UVR exposure studies, the mining environment presents a unique unexplored occupational environment.

2.3.6 Knowledge, attitude, and behaviour related to solar UVR exposure

Occupational health legislation requires employers to educate, inform, and train employees about the occupational hazards they might encounter, the related health risks, and the strategies they can employ to prevent or mitigate exposure (Republic of Namibia, 2007; ILO, 2018). Sun safety training, in addition to improving knowledge and attitude, tends to change workers' perception of workplace safety culture and consequently change their behaviour when the training is conducted in groups (Cavazza and Serpe, 2010; Durand *et al.*, 2022). Woolley *et al.* (2008) found that workers employed by a company with a mandatory sun protective policy had a lower solar UVR exposure. Also,

a positive correlation between training and improvement in knowledge and attitudes related to photoprotection was found (Malak *et al.*, 2011). However, others have reported that training does not imply that positive behavioural changes will be a consequence supposedly gained by the knowledge (Houdmont *et al.*, 2016). Variations in the findings show that there is a need for evaluation of the effectiveness of training activities or interventions to be carried out (Rye *et al.*, 2014; Houdmont *et al.*, 2016).

People with positive attitudes towards solar UVR exposure and tanning are less likely to intentionally reduce their exposure. A positive link between how an individual perceives the risk and the intent to reduce their solar UVR has been found (Bränström *et al.*, 2004). This aspect is important for individuals with darker skin types since they not only have much less knowledge about their risk and preventive measures (Calderón *et al.*, 2019), but they also underestimate their risk (Zink *et al.*, 2018) as informed by lower incidences of skin cancer (Tod *et al.*, 2019).

Personal behavioural factors such as avoidance of exposure during peak hours, shade seeking during breaks where available, the knowledge of, and compliance to photoprotection measures, jointly have a direct bearing on the solar UVR exposure dose received by workers (Reeder *et al.*, 2013; Weihs *et al.*, 2013; Milon *et al.*, 2014; Modenese *et al.*, 2019; Peters *et al.*, 2020; Ruales *et al.*, 2022). The role of personal behaviour is observed in large differences found in solar UVR exposure between participants in the same work environment (Dadvand *et al.*, 2011; Bodekaer *et al.*, 2015).

2.4 Health effects of solar UVR

Solar UVR, depending on the level and duration of exposure, has both positive and negative health effects (Webb *et al.*, 2010).

2.4.1 Health benefits of solar UVR exposure

The production of Vitamin D as a benefit of solar UVR exposure is well documented. Additional benefits such as a feeling of well-being and the use of both natural and artificial UVR in phototherapy are discussed in this section.

2.4.1.1 Vitamin D production

Exposure to solar UVR contributes to 90% of serum Vitamin D production, which plays a vital role in maintaining good bone health and preventing certain cancers, type I diabetes, heart disease, and osteoporosis (Holick, 2004; Diffey, 2006; Marshall and Byrne, 2017). In the intestine, vitamin D facilitates the absorption of calcium and phosphorus essential for most physiological functions (Mead, 2008).

Sources of vitamin D include foods such as fatty fish, fortified milk, and supplementation. Since diet and supplementation may be affected by issues of malabsorption in the gastrointestinal system, exposure to solar UVR remains the main source of Vitamin D₃ (Holick, 2004; Wolpowitz and Gilchrest, 2006; Herrick *et al.*, 2019). The absorption of UVB rays from solar UVR breaks the B ring in 7-dehydrocholesterol in the skin's plasma membrane creating pre-Vitamin D₃, which then undergoes isomerisation to become Vitamin D₃ in a heat-sensitive but non-enzymatic manner (Birkle, 2015; Herrick *et al.*, 2019). After its formation, vitamin D₃ is released from the plasma membrane into the extracellular environment, where the vitamin D-binding protein transports it into the dermal capillary bed (Birkle, 2015). Vitamin D₃ is either stored in the adipocytes of body fat or processed in the liver to form 25-hydroxyvitamin D, the form of vitamin D in circulation. Further transformation into 1,25-dihydroxy vitamin D occurs in the kidneys that are responsible for the regulation of calcium metabolism (Holick, 2009).

Adequate production of vitamin D is determined by how much of the skin is exposed to the sun, season, skin phototype, certain medications, age of the person and the ambient solar UVR (Lucas *et al.*, 2006; Judd and Tangpricha, 2009). It is estimated that a 10-minute daily exposure at noon would be sufficient to ensure that people with lighter skin types will have sufficient 25-hydroxy Vitamin D circulation during winter (>25 nmol/l), provided that about 35% of their skin was exposed (face, hands, arms and lower legs) (Webb *et al.*, 2018a). A population-wide study in New Zealand by Scragg *et al.* (2016) on the other hand showed that exposure as low as less than 2 SED per week may help improve the vitamin D status of individuals. The corresponding time for those with darker skin types (Fitzpatrick skin phototype V) is approximately 25 minutes of daily exposure

(Webb *et al.*, 2018b). The higher melanin content in the epidermis of darker skin types competes with 7-dehydrocholesterol for UVB absorption, leading to lower vitamin D₃ levels and the need for supplementation (Ames *et al.*, 2021). Hence, Wyatt *et al.* (2015) purported that more evidence on dose-response that considers different ages and skin types is required for sufficient exposure duration recommendations to be made. Also, the ability to produce vitamin D₃ decreases with age despite regular solar UVR exposure. Therefore, only the highly active and avid outdoor people will have adequate vitamin D₃ levels. Exposure to solar UVR and serum vitamin D₃ has a non-linear association, suggesting that overexposure carries little additional benefit (Scragg *et al.*, 2016).

2.4.1.2 Non-vitamin D benefits

Individuals have reported a feeling of calmness after exposure to solar UVR in a solarium or sunroom (Feldman *et al.*, 2004). Although serotonin is probably involved in mood changes, the precise mechanism behind the changes in serotonin levels is not well understood. The impact of sunlight reaching the central nervous system through the retina (known as the retinoraphe tract) offers a possible explanation. Nonetheless, findings suggest that the skin might also play a role in influencing serotonin (Sansone and Sansone, 2013). One of the factors that turn people to tanning habits is the belief that a tan improves their looks (Sivamani *et al.*, 2009; Nkogotse *et al.*, 2019). Jussila *et al.* (2016) showed that an increased expression of β -endorphins in human skin epidermal keratinocytes occurred with exposure to narrow-band UVB, making it a driver for addictive behaviour. Also, to individuals with seasonal affective disorders, the exposure to solar UVR such as a walk outside, was rated higher than low-dose artificial light. This was accompanied by lower cortisol levels (Wirz-Justice *et al.*, 1996). Furthermore, the reward centres in the brain were found to be activated by a session of solar UVR as opposed to artificial UVB/UVA in tanning sessions (Harrington *et al.*, 2012).

Phototherapy is used in the treatment of different skin conditions (Svobodova *et al.*, 2006). The current phototherapy treatments comprise narrow-band UVB radiation (311–313 nm), UVA radiation combined with psoralen (PUVA), UVA1 radiation, and photopheresis (extracorporeal photochemotherapy) (Lim *et al.*, 2015). In a study that evaluated UVA1

treatment for inflammatory diseases, sclerotic disease, and neoplastic dermatological diseases, positive responses were found in 85% to 89% of the individuals who received the treatment across the different diseases (Ronen *et al.*, 2023).

2.4.2 Negative effects of solar UVR on the skin

UVB causes harmful effects on the skin and can lead to the formation of tumours, despite only about 5% of UVB reaching the surface of the earth. (Modenese *et al.*, 2016; Wright *et al.*, 2019). Noticeably, solar UVR impacts primarily the skin and eyes (Mofidi, 2018). The negative effects of solar UVR exposure include both acute and chronic effects.

2.4.2.1 Erythema

Acute exposure to solar UVR is known to cause erythema (sunburn), described as an inflammatory response of the skin, characterised by reddening that serves as a good warning to signal overexposure. Thus, the dose-response resulting in erythema is the most studied concept (Young, 2006) since it is a well-known risk factor for the development of skin cancer (Milon *et al.*, 2014). Wu *et al.* (2016) found that individuals with a history of severe sunburn are at a higher risk of developing cutaneous malignant melanoma (CMM). This risk is higher in men than in women. Also, the risk is more closely linked to sunburn on the trunk than other body sites (Wu *et al.*, 2016). A different cohort study that focussed on women indicated an increased risk for melanoma and SCC occurring later in life because of a lifetime of severe sunburn (Lergenmuller *et al.*, 2022). There is a ten times difference in the sensitivity to erythema between light and darker skin types (Diffey *et al.*, 2019). However, the difficulty in perceiving sunburn in darker skin types, results in incidents of overexposure being missed (Lucas *et al.*, 2016; Lucas *et al.*, 2018). A South African study by Wright *et al.* (2013) found that there is a potential risk of sunburn for outdoor workers of all types of skin throughout the year, while those with lighter types of skin (phototypes I to III) shown in Table 1, face a similar risk during the winter months.

2.4.2.2 Immunosuppression

The immune system is the body's defence mechanism against infections and cancers and is usually highly effective in the recognition and response to foreign microorganisms and initiation of tumours (WHO, 2002). After skin exposure to radiation, various chromophores have been discovered that trigger local anti-inflammatory and immunosuppressive processes, leading to a series of immune alterations (Poon *et al.*, 2005; Hart *et al.*, 2019). Both UVA and UVB are known to cause immunosuppression through different mechanisms and doses (Greinert *et al.*, 2015). In human skin, local immunosuppression peaks at a wavelength of 300 nm for UVB exposure, while for UVA radiation, it peaks at 370 nm (Matthews *et al.*, 2010; Damian *et al.*, 2011). Since sunlight has a significantly larger quantity of UVA compared to UVB radiation, the solar immunosuppressive response is three times stronger for UVA than for UVB (Damian *et al.*, 2011).

UVA generates reactive oxygen and nitrogen species that harm DNA, proteins, and lipids, leading to a rise in prostaglandin E2 levels (Halliday, 2005). On the other hand, UVB influences the immune system by using immunosuppressive mediators, enhancing the production of suppressor cells, and disrupting the function of effector and memory T-cells (Norval *et al.*, 2008; Greinert *et al.*, 2015). It also seems that preventing sunburn or erythema does not typically guard against alterations in the skin's immune response and the immunosuppression caused by solar UVR exposure. Hence, it would be wise to adopt personal protective measures, even with tanned skin, to mitigate the potential risks associated with immunomodulation, such as reduced control over skin tumours and infectious diseases (Norval *et al.*, 2008). Jointly, UVA and UVB cause immune suppression at levels much lower than those causing sunburn, with men being significantly more vulnerable to this suppression than women (Damian *et al.*, 2008). Immunosuppressed individuals, particularly organ transplant recipients who require long-term immunosuppressive drugs, exhibit a heightened risk of developing keratinocyte cancer (KC) (Friman *et al.*, 2022).

2.4.2.3 Premature Ageing

The continuous sloughing off of corneocytes, which represents the last phase of keratinocyte differentiation, is a distinctive characteristic of the skin, enabling ongoing self-renewal (Wlascheck *et al.*, 2001). Ageing is an integral (intrinsic) part of life that produces undesirable changes to all organs of the body including the skin. One of the negative effects of chronic exposure to solar UVR on the skin is photoaging that overlaps with the normal ageing process. Areas of the body such as the face, neck, forearms, and back of the hands show signs of ageing much earlier than the rest of the body. As a result, reference is made to intrinsic (natural) and extrinsic ageing (caused by external factors). Intrinsically aged skin and skin affected by photoaging show clinical differences, yet they possess comparable biochemical and cellular traits, such as reactive oxygen species production, DNA damage, and breakdown of the extracellular matrix (Rittié and Fisher, 2015).

The apoptosis of stem cells in the basal layer and hair bulge caused by solar UVR exposure is theorised to lead to thinning of the epidermis, delayed wound healing, and loss of pigmentation in pseudo scars. In contrast, the increased melanin production seen in ageing melanocytes (Bandyopadhyaya and Medrano, 2000), may explain the phenomenon of bronzing, or the lasting tan effect noticed in photoaged skin of some individuals with darker skin types. Poor skin elasticity in younger individuals aged between 20 to 29 years that are exposed to solar UVR is an indication of negative health effects of solar UVR exposure (Łastowieka-Moras *et al.*, 2014). Although the skin of all phototypes experiences premature ageing, lighter skin types display more pronounced effects, an aspect that is related to the skin's ability to repair acute DNA damage (Gilchrest, 2013). Furthermore, photoaging is related to the risk of skin cancer (Wright *et al.*, 2015).

2.4.2.4 Pigmentation disorders in darker skin types

Although numerous epidemiological studies have shown a lower incidence of skin cancer in individuals with darker skin compared to those with lighter skin types, the complexity of the relationship between pigmentation and photoprotection has emerged (Brenner and

Hearing, 2008). Despite this increased protection, individuals with darker skin types are more likely to develop certain pigment defects. Pigment disorders include post-inflammatory hyperpigmentation (PIH) and melasma as the two most common conditions in this category, disproportionately affecting individuals with dark skin. PIH is characterised by the formation of hyperpigmented macules and patches after skin damage such as acne and eczema, or injury such as trauma and sunburn (Kaufman *et al.*, 2018; Passeron *et al.*, 2021). The notable impact of hyperpigmentation disorders is the negative emotional and psychological effects it has on affected individuals (Maymone *et al.*, 2017). This aspect is important since most of the people in Namibia have darker skin types.

2.4.2.5 Skin cancer

Skin cancer is divided into keratinocyte carcinoma (KC) and cutaneous malignant melanoma (CMM). Keratinocyte carcinoma is a better term that refers to carcinoma related to keratinocytes as opposed to the non-specific older term, which included Merkel cell carcinoma, dermatofibrosarcoma, cutaneous lymphoma, angiosarcoma and others that are not related to the keratinocytes (Beatson *et al.*, 2019). KCs, the most common type of malignancy, is divided into basal cell carcinoma (BCC) and cutaneous squamous cell carcinoma (cSCC) (Leiter *et al.*, 2014; Karimkhani *et al.*, 2015).

Evidence from experimental studies indicates that exposure to solar UVR, a type 1 carcinogen (IARC, 2012), influences the progression of CMM and KCs through direct (UVB) or indirect (UVA) DNA damage. BCC accounts for 80% of these malignancies, while cutaneous squamous cell carcinoma (cSCC) makes up the remaining 20% (Villani *et al.*, 2022). BCC primarily develops on skin that has been exposed to solar UVR for extended periods, such as the face and neck areas (Schmitt *et al.*, 2018; Loney *et al.*, 2021). Recreational solar UVR exposure on its own was not linked to BCC (Schmitt *et al.*, 2018). Though uncommon, BCC can also appear on mucous membranes or the palms or soles of the limbs. It generally progresses slowly and rarely spreads to other parts of the body (Nandyal *et al.*, 2014). Cutaneous squamous cell carcinoma on the other hand, develops within the middle and outer layers of the skin's squamous cells with the head

and neck being the most frequently impacted areas of the body. Unlike BCC, cSCC presents a higher risk because of its aggressive characteristics and potential to spread. The primary cause of both BCC and cSCC is extended exposure to solar UVR without protection (Laishram *et al.*, 2010). Also, the risk of all types of KCs increases with increasing ambient solar UVR (Briceno *et al.*, 2020). Findings showed that outdoor professionals such as farmers, gardeners, and mountain guides face varying levels of risk for KCs and exhibit diverse risk behaviour towards solar UVR exposure (Zink *et al.*, 2018). In 2019, the proportion of solar UVR occupationally exposed individuals in Namibia stood at 26.86% (95% uncertainty range 22.72–31.0%) (Pega *et al.*, 2023). With respect to gender, studies present conflicting results, indicating that more men are affected by KCs (Badiu *et al.*, 2023), whereas others reported that women are largely impacted (Laishram *et al.*, 2010). In Namibia, the reported age-standardised rates (ASR) incidences of KCs for men were higher (22.0 per 100 000) than that of women (9.7 per 100 000) in 2022 (IARC, 2024). Consideration of the impact of solar UVR on the skin and early diagnosis of KCs is important because individuals with KC are at even greater risk of developing melanoma skin cancer (Ali *et al.*, 2013).

Cutaneous malignant melanoma is a cancer that originates from melanocytes, which are pigment-producing cells found in the basal layer of the epidermis. CMM is more common in people with lighter skin phototypes. Additional risk factors include exposure to solar UVR, immunosuppressive conditions, and the presence of many moles, especially dysplastic types (Matthews *et al.*, 2017). The areas of skin that experience erythema during adolescence are at higher risk of CMM (Burns *et al.*, 2019). It represents the most aggressive form of skin malignancy, known for its quick development and significant potential to metastasise (Michalak-Mińska *et al.*, 2022). CMM accounts for over 90% of deaths related to skin diseases. Globally, CMM continues to demonstrate rising incidence rates that are surpassing other cancers to the extent that it is ranked as the 15th most common cancer worldwide (Burns *et al.*, 2019). It is also projected that by 2040 there will be a 50% rise in new cases of CMM and a 60% increase in deaths related to it (Arnold *et al.*, 2022). The CMM incidence rate varies significantly across countries due to differences in sun exposure levels and skin phenotype variations (Burns *et al.*, 2019). In Namibia, the

ASR for CMM was 4.1 per 100 000 in 2022 (IARC, 2024). The key to a good prognosis is early detection and as such outdoor workers should be made aware of these malignancies and the importance of self-examination (Naik, 2021). The occurrence of skin cancer due to intense and chronic exposure to solar UVR at work is recognised as an occupational disease in several countries including Australia, Denmark, Germany, Austria, Croatia, Portugal, Italy and Romania (John *et al.*, 2016; Trakatelli *et al.*, 2016; Modenese *et al.*, 2018). The call made to recognise occupational skin cancer as a reportable disease in South Africa (Wright *et al.*, 2015) should be extended to African countries.

2.4.3 Negative health effects on the eyes

Sunlight from UVR is essential for visual perception (Ivanov *et al.*, 2018) while it is also responsible for negative effects on the eyes (Young, 2006). Although different skin types are affected differently by solar UVR, the sensitivities of the eyes are the same (ICNIRP, 2010). Concerning the multi-layers of the eye, the radiation received on the retina and the cornea may be attenuated by the intermediate layers and lens and vitreous humour respectively (Johnson, 2004). When these protective mechanisms fail, different eye conditions develop, particularly during long-term exposure, causing the accumulation of oxidative damage due to solar UVR radiation (Ivanov *et al.*, 2018).

Acute effects, photokeratitis, appear six to 12 hours after exposure and can be compared with sunburn of the skin (Young, 2006). Photokeratitis is reversible and does not leave long-term damage to the eyes or vision. In extreme cases, photokeratitis is characterised by snow blindness (WHO, 2002). Chronic exposure causes cortical cataracts, pterygium, SCC of the cornea and conjunctiva, and cancer of the eyelids (Modenese and Gobba, 2018; Chawda and Shiende, 2022). Pterygium is the most common chronic eye disease that develops from the corner near the nose and is characterised by itchiness, burning and the appearance of wing-shaped growth on the conjunctiva. In its progression, it covers the pupil and results in blurred vision (Wright and Norval, 2021).

Cataracts are the leading cause of blindness in the world. The proteins in the eye lens disintegrate, clump, and accumulate pigments that overshadow the lens and ultimately

cause blindness. Although most individuals age differently, exposure to solar UVR appears to be an important risk factor for cataract development (Löfgren, 2017).

2.5 Occupational Exposure Legislation

Most countries in the world lack a specific legal occupational limit for exposure to solar ultraviolet radiation (John *et al.*, 2021). For many years, the ICNIRP has recommended a range of 1.0 to 1.3 standard erythemal dose (SED) based on the International Commission on Illumination (CIE) action spectrum as an exposure guideline for 8 hours (CEN, 2008; ICNIRP, 2010). Standard erythemal dose is a standardised measure of erythemogenic UV radiation which can be used for all skin phototypes (where 1 SED is equivalent to an erythemally effective radiant exposure of 100 J/m²) (CIE 125, 1997). The ICNIRP exposure guideline was adopted as an occupational exposure limit for solar ultraviolet radiation exposure in 2006 (ARPANSA, 2006). The exposure guideline is aimed at the prevention of acute health effects on the skin and eyes (ISO, 2019). Consequently, the exposure guideline ought to be applied carefully in Africa, as it fails to safeguard against long-term exposure of the eyes and immune system to excessive solar UV radiation (Agbai *et al.*, 2014; Fajuyigbe and Young, 2016). Among the aspects raised in the Global Call to Action to Protect Outdoor Workers from Skin Cancer by Solar Ultraviolet Radiation Exposure (Röcken *et al.*, 2023) that are relevant to the mining operations in Namibia, is the efficient protection of outdoor workers through the formulation and enforcement of a legislative framework for occupational solar UVR exposure by the World Health Organisation (WHO)

2.6 Measurements of Solar UVR Exposure

Occupational exposure of outdoor workers to solar ultraviolet radiation is an important aspect of care in general occupational health (Wright *et al.*, 2011). Therefore, the need to measure outdoor worker exposure to solar UVR is relevant (Carey *et al.*, 2014; John *et al.*, 2016). Extrapolation to the outdoor mineworkers of Namibia from international studies will be nearly impossible since individual exposures vary with latitude, altitude, time of day, and season. Different activities also require varying periods spent outdoors, and

exposed body positions will differ with postures assumed in different occupations (Lucas *et al.*, 2008; Vernez *et al.*, 2015).

Additional factors such as clothing habits and individual behaviour contribute to dose differences (Lucas *et al.*, 2008) and these factors have not been studied in Namibia. It should be noted that many previous studies and public health initiatives have focused on populations with lighter skin types as a reference or gold standard (Goldenberg *et al.*, 2015). Therefore, the adaptation of the results of these studies to other countries with different skin types is questionable.

Comparing exposure from different studies is problematic due to differences in study design, anatomical attachment of dosimeters, and solar UVR that vary between sites (Kimlin *et al.*, 2007). Moreover, Carey *et al.* (2014) stated that not enough has been done to contribute to the information on the actual exposure of outdoor workers in countries such as Australia. Neither ambient UVR and latitude nor estimation of solar UVR can fully estimate the amount of solar UVR since within-city variations are not considered (WHO, 2003; Lucas *et al.*, 2006). Furthermore, differences in the reporting of solar UVR exposure create difficulties in comparisons between studies (Perdersen *et al.*, 2021). Therefore, outdoor opencast mineworkers at the selected mining operations will benefit from knowing the baseline levels of solar UVR exposure and the associated postures on which protective measures could be based.

2.6.1 Personal Solar UVR Dosimetry

Understanding exposure to solar UVR requires studies quantifying personal exposure to different environments and activities (Wainwright *et al.*, 2017). Radiometers can be used to accurately measure solar UVR exposure in fixed locations. However, given the importance of local environmental conditions, personal dosimeters are ideal. The stability of broadband radiometers used in meteorological measurements remains necessary since they provide reference measurement (Cherrie and Cherrie, 2022). To achieve the objectives of solar UVR exposure measurement, the principles of precision and accuracy are of utmost importance (Diffey, 2002).

Personal dosimeters are devices that produce a direct response to incident radiation doses. Dosimeters are calibrated so that their response is in accordance with a specific action spectrum. Therefore, this explains why personal dosimeters have the same spectral response as that of human skin (Geiss *et al.*, 2003). Polysulphone and electronic dosimeters are two examples of personal dosimeters that are commonly used in several studies (Diffey, 2020).

2.6.1 Polysulphone dosimeters

The polysulphone dosimeter badge (referred to as the PSF badge hereafter) has been widely used as a personal dosimeter in various studies (Diffey, 2002; Gies *et al.*, 2009; Linde *et al.*, 2021). The PSF badge contains a film (40 μm in thickness) mounted in a cardboard or plastic case. The film undergoes photodegradation, which changes the optical absorbance when exposed to UVR. The change is then quantified with a UV-visible light spectrophotometer at a wavelength of 330 nm. The PSF badge's spectral response is the same as the erythemal action spectrum (Cherrie and Cherrie, 2022).

Calibration is achieved by placing 48 PSF badges with pre-determined absorbance next to a calibrated solar UVR Biometer that measures biologically effective irradiance in minimal erythemal dose (MED). The MED is then converted to Joule/m^2 (1 MED = 210 Joule/m^2). One PSF badge is removed at 10-minute intervals and post-exposure absorbance is measured. When post-exposure absorbance cannot be measured immediately, then the PSF badges are kept in brown envelopes to prevent exposure to light. The storage of badges for longer than 24 hours results in a dark reaction taking place, requiring a correction of 5% higher and this value must be subtracted from the measured absorbance (Geiss *et al.*, 2003).

A calibration curve is created by plotting the change in absorbance against the irradiance measured with the broadband solar UVR instrument in J/m^2 .

The calibration equation obtained from the calibration curve is used to convert the change in absorbance to erythemally weighted radiation amount using equation 1 (Geiss *et al.*, 2003).

$$\text{Radiation amount } J/m^2 = a(\Delta A)^2 + b(\Delta A) \quad [\text{Equation 1}]$$

Where: ΔA = Absorbance at 330 nm after exposure – Absorbance at 330 nm before exposure

Finally, solar UVR doses are then converted to SED where 1 SED = 100 J/m² of erythema effective UVR exposure spectrally weighted with the erythema action spectrum (CEN, 2008). There are errors associated with a PSF badge that include a coefficient of variation of 1.4% within the same batch treated in the same way, the period allowed between exposure and the absorbance measurements, as well as contamination of the film caused by, for example, grease from the hands and dust (Geiss *et al.*, 2003).

2.6.2 *Electronic Dosimeters*

The electronic dosimeters used in this thesis are manufactured at the Electrical and Computer Engineering Department of the University of Canterbury, Canterbury, New Zealand. They are small (35 x 10 mm), weigh only 20 g, can be reused, and are powered by a 3V lithium battery that can operate for three months. They also show a linear response with exposure as opposed to a logarithmic response and have high sampling rates due to the presence of an on-board memory of 128 kilobytes or 64 000 data samples, which can be equated to 12 to 14 days at varying periods between eight- and 60-seconds sampling. Data is downloaded to a computer at the end of the measurements for each day. The small size of the badges allows them to be pinned onto clothing or worn with a velcro arm or wrist strap (Allen and McKenzie, 2005). They measure personal exposure to solar erythema UVR at wavelengths between 290 and 400 nm (Nurse *et al.*, 2015). The electronic dosimeters are calibrated by comparing their output to the erythemally weighted UVR obtained with a broadband radiometer before and after measurements.

The other electronic dosimeter that was not used in this thesis is the GENERation and Extraction System for Individual Exposure Dosimeters (Genesis-UV) unlike other dosimeters, effectively measures both UVA and UVB radiation and can be used for extended periods of measurement (Wittlich, 2015; Wittlich *et al.*, 2023).

2.6.2 Hand-held ultraviolet index (UV Index) monitors

An option of using hand-held UVI monitors exists alongside personal measurements. These are battery-operated and provide an instantaneous reading that is then recorded and may be used for correlation with personal measurements (WHO, 2003). The UV index was developed as a means of communicating the intensity of solar UVR to the public. It was collaboratively developed by the WHO, the United Nations Environment Programme, and the International Commission on Non-Ionizing Radiation Protection, and standardised by ISO/CIE (International Organization for Standardization/ International Commission on Illumination). The index represents the sun's erythemal power as follows:

$$UV\ index = 40 \times \text{erythemal effective power of the sun (Watt/m}^2\text{)}$$

[Equation 2]

A clear sky's UV Index around solar noon typically ranges from 0 to 12 at the Earth's surface (IARC, 2012). Following the WHO SunSmart programme, a UV index between 0-2 means that it is safe to go outside, 3 to 7 implies that photoprotective measures should be applied before one goes outdoors, while 8 and above means it is not safe to go outside, and avoidance of peak exposure should be practised. The SunSmart Global UV free application is also available for download on smartphones, making information easily accessible for sound decision-making (WHO, 2022).

2.6.3 Comparison between PSF and electronic dosimeters

Differences in the size and weight of different types of dosimeters may be decisive in the choice of the most appropriate system. When comparing PSF to electronic dosimeters in solar UVR exposure measurements, PSF dosimeters were found to provide dose values higher than electronic dosimeters overall. The differences between these two dosimeters

ranged from 20% to 30%. In addition, electronic dosimeters produced a smaller standard deviation, pointing to higher reliability (Strehl *et al.*, 2021). PSF badges provide a measurement of the total exposure of an individual during the sampling period. In contrast, electronic dosimeters allow for measurement over extended periods while showing fluctuations in solar UVR dose over time (Diffey, 2020).

2.6.4 Personal exposure measurements from published studies

The results from previous studies are presented in Table 2 and these show differences in types of dosimeters, occupations, attachment positions, seasons, and the measured dose. Comparisons show that more studies have concentrated on warmer months due to the anticipated lower solar UVR levels during winter (Cherrie *et al.*, 2021; Linde *et al.*, 2022). However, in a study where winter measurements were included, winter exposure was higher than the summer dose (Downs *et al.*, 2019). Also, solar UVR exposure as a percentage of ambient solar UVR was found to be twice as high as that in summer (Neale *et al.*, 2010). Thus, the inclusion of winter solar UVR exposure measurements is necessary for a complete exposure pattern to be established. Observed variations in solar UVR exposure of different body positions (Siani *et al.*, 2011) and among the different occupations (Gies *et al.*, 2014), and countries (Wittlich *et al.*, 2020) highlight the importance of these aspects in exposure studies.

Table 2. A summary of findings from personal solar UVR exposure measurement studies (in chronological order and given as average exposure and range where applicable).

Authors	Country	Dosimeter type	Season	Occupation	Body position	Solar UVR exposure
Kimlin <i>et al.</i> , 2006	Australia	PSF	Winter	Cyclists	Vertex	1.8 SED
					Hand	1.28 SED
Neale <i>et al.</i> , 2010	Australia	PSF	Summer	Outdoor (not specified)	Chest, shoulder	1.4 SED
			Winter			0.91 SED
Siani <i>et al.</i> , 2011**	Italy	PSF	Spring	Vineyard workers	Arm	30 – 60%
			Summer		Back	53 – 87%
					Arm	19 – 43%
					Back	36 – 77%
Gies <i>et al.</i> , 2014	New Zealand	Electronic	Winter	Construction	Chest and wrist	0.2 - 4.3 SED
				Physical education teachers		0 - 7 SED
				Farmers		0 - 10 SED
Sun <i>et al.</i> , 2014	Australia	PSF	Winter-Summer	Various (not specified)	Wrist	0.01 – 21 SED
Grandahl <i>et al.</i> , 2018	Denmark	Electronic	Summer	Construction, gardeners, roofers, postal, road, dockworkers, carpenters and masons	Wrist	214.2 SED*
Downs <i>et al.</i> , 2019	Australia	PSF	Winter	Teachers	Back of neck	0.91 SED
			Summer			0.63 SED
Modenese <i>et al.</i> , 2019	Italy	Electronic	summer	Fishermen	Back of head	2.5 – 65.3%
Nkogatse <i>et al.</i> , 2019	South Africa	Electronic	Spring	Car guards	Upper arm	0.29 SED
Moldovan <i>et al.</i> , 2020	Romania	Genesis-UV	Spring & autumn	Construction	Upper arm	1.28 – 6.5 SED
Wittlich <i>et al.</i> , 2020	Romania	Genesis-UV	Summer to autumn	Masons	Upper arm	148 – 680 J/m ²
	Italy					42 – 640 J/m ²
	Croatia					41.8 – 473 J/m ²
	Denmark					88.1 – 400 J/m ²
Cherrie <i>et al.</i> , 2021	Britain	Electronic	Summer	Construction	Back of the head	2.0 SED
Linde <i>et al.</i> , 2022	South Africa	PSF	Autumn	Outdoor farmworkers	Head	7.7 SED
			Spring		Head	11.6 SED
			Summer		Head	13.9 SED

% = solar UVR exposure as percentage of ambient solar UVR; * = cumulated dose; **solar UVR exposure as a percentage of ambient solar UVR was reported.

2.7 Measures used to control exposure to solar UVR

The occupational hygiene hierarchy of controls offers a variety of protective methods aimed at reducing exposure of outdoor workers to solar UVR that include avoidance of exposure during peak periods, availability of shade structures, clothing, wide-brimmed hats, sunglasses, and sunscreen (Madgwick *et al.*, 2011).

2.7.1 Avoidance of exposure

According to Diffey (2023), 50% to 60% of total daily solar UVR exposure is received during the peak period between 10:00 to 14:00. Thus, avoidance of solar UVR exposure during peak periods of the day is considered the first line of defence (Gies, 2007; Ruales *et al.*, 2022). Unlike in everyday life, occupational exposure to solar UVR is not easily avoidable (Łastowicka-Moras *et al.*, 2014), since outdoor workers are not usually free to schedule their hours (Merin *et al.*, 2022).

2.7.2 Shade structures

A shade is described as an intervention that is natural or built to protect against solar UVR exposure (Holman *et al.*, 2018). Such measures are considered the first line of defence in reducing the total exposure to ultraviolet radiation of both the eyes and the skin. However, the space required to erect the shade structure may not be available in certain types of work environments, such as construction sites, and shade may not be usable by certain occupations (Mofidi *et al.*, 2021). To overcome the limitations, consideration for the location and type of shade should be done during the development process with exposure to solar UVR included among other occupational hazards (Parisi and Turnbull, 2014; Holman *et al.*, 2018). Consequently, the shade provided will fit the purpose for which it is planned (Downs *et al.*, 2019).

The level of solar UV protection offered by a shade structure is determined by its height, size, shape, presence or absence of overhang, and the type of ground surface that may influence the reflectivity of solar UVR (Holman *et al.*, 2018).

The overall effectiveness of a shade can be determined through its protection factor (PF), calculated using the formula taken from Gies *et al.* (2013):

$$PF = \frac{\text{solar UVR in full sun}}{\text{solar UVR under the shade}} \quad \text{[Equation 3]}$$

According to Parisi and Turnbull (2014), an ideal shade offers a PF of 15 or higher. Using PSF badges in a study conducted by Gies *et al.* (2013), the different shade structures had PF values that ranged between two and 16 with higher PF values obtained from larger structures. Trees, on the other hand, provided significantly lower PF values (Parisi *et al.*, 2002). Among the available options to reduce exposure to solar UVR, the use of shaded areas and limiting exposure by New Zealand workers were found to be poor (Reeder *et al.*, 2013). Thermal comfort where ambient temperatures are high could be a factor that influences the shade-seeking behaviour of workers (Parisi and Turnbull, 2014). However, the construction sector in Canada found that shade is an effective measure of reducing solar UVR exposure and the associated risk of skin cancer and sunburn (Peters *et al.* 2016).

2.7.3 Information, instruction and training

Educating workers about the dangers of chronic exposure to solar UVR and the benefits of protection is an important aspect of their occupational health (ILO, 2018; Baczynska *et al.*, 2020). The amount of solar UVR received by the body sites, the period of exposure, and latitude must be included in awareness campaigns (McKenzie and Lucas, 2018). Workers should receive training in appropriate clothing and eyewear for their type of work (ICNIRP, 2010). In recent times, awareness of skin cancer has been identified as one of the most important drivers of the use of sun protection measures (ICNIRP, 2010; Diffey *et al.*, 2020).

The perception of outdoor workers to workplace support, such as education, improves compliance with protection measures in New Zealand and Australia (Reeder *et al.*, 2013; Rye *et al.*, 2014). Similarly, Canadian ski resort workers who received training on the Sun Smart programme five to seven years earlier scored higher on the sun protection

questionnaire than those who did not (Walkosz *et al.*, 2015). Since differences between men and women were found concerning the use of protective measures, awareness campaigns must be implemented with this in mind (Diffey *et al.*, 2020). Therefore, education on protection measures and behaviour modification are important factors (Neale *et al.*, 2010) particularly because general knowledge of risk and protection methods was found to be lacking in various workplaces (Hault *et al.*, 2016; Nkogatse *et al.*, 2019). For education and training programmes to be useful for outdoor workers, they have to be tailored to the context of the workplace (Marrett *et al.*, 2016, Fazel *et al.*, 2023).

2.7.4 Recommendations for personal protection

Individual skin phototypes and the type of work performed by outdoor workers must be considered when determining protection measures since it has a direct bearing on the appropriate type of protection measures workers can use (Lucas *et al.*, 2006; Makgabutlane and Wright, 2015). One of the simplified measures available to raise public awareness regarding the measures necessary for protection, is the UV index (WHO, 2003). The World Health Organisation's (WHO) INTERSUN programme recommends the use of protection when the UV index is at level three or higher. However, reliance on this measure in the absence of any other information is problematic, as shown by the findings of a study by McKenzie and Lucas (2018). In this study, the daily dose of UVR in winter was shown to be higher than the threshold required for sunburns to occur in lighter skin types when the UV index was below the protection threshold. In addition, for areas of the body exposed to the sun, such as the face, neck, and head, exposure may be much higher than the levels obtained from measuring exposure on horizontal surfaces.

2.7.4.1 Clothing

Clothing is considered one of the easiest ways to reduce exposure to solar UVR (ICNIRP, 2010). The effectiveness of clothing is evaluated by the UV protection factor (UPF) which is similar to the sun protection factor (SPF) of sunscreen by assessing the ability of a specific garment to prevent UVR-induced erythema (Boothby-Shoemaker *et al.*, 2022). The UPF of clothing is measured by comparing the average UV radiance of naked skin to the average UV radiance of the skin protected by the fabric under review (Hoffmann *et*

al., 2001). To evaluate the effectiveness of UV protection on human skin, experiments can be performed in experimental environments controlled *in vivo* or through laboratory tests using *in vitro* instrument measurements (Bernhard *et al.* 2022). For clothing to be effective, characteristics of fabrics, such as weave, colour, weight, stretch, and wetness, must be considered (Diffey, 2002). Heavy-duty denim is preferred because it provides high ultraviolet protection factors (UPF). The darker the colour of the clothing, the higher the level of sun protection. In the case of the same colour, it is important to consider the fabric's weave (Ghazi *et al.*, 2010).

Different countries have different standards related to the evaluation of the effectiveness of photoprotective clothing and labelling to indicate the level of protection. The preferable level of photoprotection is clothing with UPF ≥ 40 which offers between 97.5% to 98+% blocking of UVR. Examples of standards include EN 13758-2 applicable to European countries (Gambichler *et al.*, 2006), and AS/NZS 4399 used in Australia and New Zealand (AS/NZS, 1996).

2.7.4.2 Hats

A hat is ideal for protecting the eyes, ears and face (Reeder *et al.*, 2013). For better protection against solar UVR, hats with wide brims and caps with extended neck flaps are ideal, while limited protection is provided by baseball caps (Gies *et al.*, 2006). Hard hats, commonly known as helmets, which are issued primarily for safety reasons in most workplaces, were found to offer better protection for all facial skin zones than baseball caps. However, it should be noted that no single hat provides 100% protection for all facial zones and different positions of the sun. To this extent, wide-brimmed hats fail to protect during midday due to the sun's position being higher. During winter, the sun reaches the front part of the face due to its low position (Backes *et al.*, 2018).

Regarding usage, Peters *et al.* (2016) found that 79% of outdoor workers reported that they often or always wear hats when outdoors while other studies found lower usage of wide-brimmed hats (Pichon *et al.*, 2005; Lewis *et al.*, 2006).

2.7.4.3 Eyewear

A positive correlation has been found between different eye diseases and solar UVR exposure (Yam and Kwok, 2014). Thus, in addition to the use of hats, sunglasses are necessary for the protection of the eyes (Cestari and Buster, 2017). Also, consideration must be given to diffuse (scattered by the atmosphere) UVR solar UVR as a contributor to incident (solar energy that is received by a specific area over a period of time) solar UVR on the face (Behar-Cohen *et al.*, 2014). Sunglasses were found to offer a protection factor that was higher than prescription spectacles (Deng *et al.*, 2021). However, explanation and knowledge of both the dose-response relationship and sun protection factor are necessary to provide effective recommendations on eye protection (Backes *et al.*, 2019). The individual worker's specific aspects such as vision requirements, comfortability, and adjustability while offering adequate protection, make the choice of eye photoprotection even more complex (CDC, 2011). In comparison to the different types of sunglasses, tinted goggles were found to offer a 100% predictive protective factor (PPF) which is similar to sunscreen's SPF, in all head positions (Backes *et al.*, 2018). The protection standards for UV-A and UV-B rays are determined by the category of the lens and its luminous transmittance (τ_V) which is based on the ISO 12312-1 standard. According to this standard, a category 4 lens (R311-24) offers 100% protection against both UVA and UVB (Masili *et al.*, 2024).

Regarding compliance in the wearing of eye protection, findings from one study showed that only 31% of outdoor workers reported regular wearing of sunglasses when outside longer than 10 minutes during summer (Görig *et al.*, 2024). Similarly, South African farmers reported a low use of sunglasses (Linde *et al.*, 2021). Also, the poor use of sunglasses was more common in younger males with lower levels of school education (Görig *et al.*, 2024). A higher proportion of a cohort of outdoor workers (74%) in British Columbia reported that they always or often wore sunglasses during work (Peters *et al.*, 2016).

2.7.4.4 Sunscreen

Sunscreens are described as products designed to shield the skin from UV radiation damage by utilising active ingredients that can scatter, absorb, or reflect UV rays. Currently, sunscreens are widely used for photoprotection, containing organic or inorganic UV filters that enhance their ability to guard against UV radiation (Chavda *et al.*, 2023). In addition to clothing, parts of the body that are not covered by clothing must be protected with a broad-spectrum sunscreen which protects against both UVA and UVB (Boothby-Shoemaker *et al.*, 2022; Chavda *et al.*, 2023). The effectiveness of sunscreens is known as sun protective factor (SPF) which is calculated by comparing the amount of UV radiation needed to cause a sunburn on skin with sunscreen to the amount needed on skin without sunscreen, assuming all other conditions are the same (Latha *et al.*, 2013). Although sunscreens were initially intended to prevent sunburns, their ability to reduce UV-induced skin damage, such as solar keratosis and cSCC, has been demonstrated in different studies (IARC, 2001). However, this protection improves as the SPF increases, and as such high-level SPF sunscreens (>SPF 15) are often recommended (Autier *et al.*, 2007).

Training related to the amount and frequency of application should precede the use of sunscreen. A pilot study on the use of sunscreen by farmers showed that the use of sunscreen prevents the formation of reactive oxygen species. Furthermore, in 78% of sunscreen users, additional protective measures such as long sleeves were used (Kim *et al.*, 2017). Poor use of sunscreen was identified to be in various work settings (Pichon *et al.*, 2005; Lewis *et al.*, 2006; Peters *et al.*, 2016; Zink *et al.*, 2017) with variations reported in a review by Reinau *et al.* (2013). Thus, making sunscreen as affordable as possible, exemption from taxation, classification as essential products, better price regulation and stricter regulations on labelling and testing requirements, could improve compliance with sunscreen use (Duffy *et al.*, 2018; Conte *et al.*, 2023).

2.7.4.5 Summary of Control Measures

The study on groups of workers in the United States of America found low use of wide-brimmed hats and sunscreen in all racial groups (Pichon *et al.*, 2005). Therefore, a

multipronged approach to protecting outdoor workers covers technical risk interventions, the provision of appropriate skin photoprotection, and a modification of worker behaviour (Ruales *et al.*, 2022). Furthermore, changes in legislation and policy are required to ensure that fundamental measures are provided to protect worker health against the negative health effects of solar UVR (Lucas *et al.*, 2016).

In general, prevention programmes show a good return on investment (Mofidi *et al.*, 2021) and are said to account for a savings of US\$ 2.7 billion between the years 2020 and 2030 (Guy *et al.*, 2015) when compared to the economic burden of NMSC (Mofidi *et al.*, 2018). With limited resources allocated to protective measures against solar UVR exposure and prevention of skin cancer, understanding financial impact versus savings would be helpful for policymakers (Mofidi *et al.*, 2021). This is an important aspect seeing that high photoprotection scores were found in workplaces that required such measures (Peters *et al.*, 2016). Although the role of photoprotection in the prevention of sunburn and the long-term effects of exposure to the sun (such as photoaging and photocarcinogenesis) are well established in individuals with lighter skin types, those with dark skin types may have less of these effects, which may affect the perceived importance of practising photoprotection (Tsai and Chen, 2022). Exploration of this aspect is important in this study since individuals with darker skin types make up 87% of the population in Namibia (World Population, 2021).

2.8 Conclusion

This review of the literature shows that outdoor workers are at high risk of developing negative health effects related to chronic solar UVR exposure. Varying levels of exposure are identified in different studies with most outdoor workers receiving exposure doses that exceed the ICNIRP exposure guideline during different seasons. Incidence of all types of skin cancer is increasing worldwide. There is a lack of exposure measurements during winter. The knowledge, attitudes, and behaviour related to the health effects of solar UVR and the use of photoprotective measures, determine the degree to which outdoor workers will be protected against solar UVR exposure.

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CHAPTER 3. ARTICLE I

Title:

SOLAR ULTRAVIOLET RADIATION EXPOSURE AMONG OPENCAST MINERS IN NAMIBIA WITH THE USE OF ELECTRONIC DOSIMETERS: A FEASIBILITY STUDY.

Note: The article in the published format is included in this chapter.

Author guideline for journal, *Annals of Global Health* (excerpt)

About the journal: *Annals of Global Health* is a peer-reviewed, open access journal focused on global health. The journal's mission is to advance and disseminate knowledge of global health. Its goals are to improve the health and well-being of all people, advance health equity and promote wise stewardship of the earth's environment.

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Abstract: Structured abstract required. This should include the sections: background, objective(s), methods, findings and conclusions. The maximum word count for structured abstracts is 300 words. Please make sure that your abstract concisely explains your manuscript

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Ethics and Consent (if applicable): Research involving human subjects, human material, or human data, must have been performed in accordance with the Declaration of Helsinki. Where applicable, studies must have been approved by an appropriate ethics committee and the authors should include a statement within the article text detailing this approval, including the name of the ethics committee and reference number of the approval.

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Solar Ultraviolet Radiation Exposure Among Opencast Miners in Namibia with the Use of Electronic Dosimeters: A Feasibility Study



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1. ABSTRACT

Importance: The lack of information on exposure of opencast mineworkers to solar ultraviolet radiation, a group I carcinogen, was addressed. The feasibility of using electronic dosimeters in the determination of exposure to solar ultraviolet radiation was investigated.

Objective: The objective of the study was to determine the feasibility of measuring the occupational exposure of opencast mineworkers to solar ultraviolet radiation using electronic dosimeters.

Design: The study followed a cross-sectional design.

Setting: Measurements were carried out at two opencast diamond mining operations hereafter referred to as site A and B, located in the Karas region of Namibia.

Participants: Workers from all four outdoor occupations (bedrock, engineering, metallurgy and security) were recruited to participate in the study.

Measurements: The study was conducted over four days at each site during winter (site A: 28 June to 4 July 2018 and site B: 6-11 July 2018) in the Karas region of Namibia with 28 consenting workers taking part. The AlGaIn photodiode-based electronic dosimeters were worn above clothing on the dorsal wrists (one) and two placed on the horizontal, unshaded area from 08:00 to 16:00 for the measurement of personal and ambient solar ultraviolet radiation, respectively. Historical meteorological data for the measurement period were obtained from Solcast and Ozone Monitoring Instrument (OMI) NASA.

Results: Overall, clear skies and surface reflectivity of 0.19 were observed for both study sites.

The mean ultraviolet indices were 2.43 (0.06-4.51) and 2.24 (0.09-4.88) for site A and B, respectively. Findings of valid measurements from nine participants showed the

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mean total daily personal solar ultraviolet radiation exposure of 1.9 ± 1.0 (1.01–1.57) standard erythemal dose (SED) for site A and 3.4 ± 2.6 (3.39–7.28) SED for site B.

Conclusions and Relevance: Personal solar ultraviolet radiation exposure above the occupational exposure limit (OEL) demonstrated the need to include the winter season in planning for protective measures for skin and eyes, since workers are at risk of excessive exposure to solar ultraviolet radiation.

2. **BACKGROUND**

This study focused on the occupational exposure to solar ultraviolet radiation of mineworkers in opencast (also known as open pit) diamond mining operations in Namibia. According to the most recent definition [1], opencast mineworkers are typical outdoor workers since they spend more than 22% of their work shift outdoors. Occupational exposure to solar ultraviolet radiation, a group I human carcinogen linked to skin cancer [2], and negative effects on the eyes [3], represents a neglected health risk for outdoor workers [4]. The lack of an occupational exposure limit (OEL) for solar ultraviolet radiation exposure in African countries, including Namibia [5, 6] exacerbates the plight of exposed workers. Overall, the proportion of occupationally exposed individuals in Namibia stood at 26.86% (95% uncertainty range 22.72-31%) in 2019, while the population attributable percentage of deaths due to occupational solar ultraviolet radiation exposure-related non-melanoma skin cancer (NMSC) is 34.12% (26.23-43.51%) [7]. In Africa, cases of cataracts accompanied by vision impairment and cataract blindness are estimated to increase to 32 million and 8 million, respectively, by 2030 [8]. Thus, exposure to solar ultraviolet radiation and subsequent occupational health risk of approximately 9000 employees, who played a vital role in contributing towards the 14% contribution to the gross domestic product of Namibia's mining industries at the time of the study [9], are not getting the attention that is warranted.

Therefore, this study aimed to explore the feasibility of measuring occupational exposure of opencast mineworkers to solar ultraviolet radiation in two mining chamber operations in Namibia using electronic dosimeters.

3. **METHODS**

ETHICAL CONSIDERATIONS

Ethics approval for this cross-sectional study was received from the Namibia Ministry of Health and Social Services (reference: 17/3/3/CR) and the Health Research Ethics Committee of the North-West University, South Africa (reference number: NWU-00031-17-A1). The researcher presented the study objectives, methods, confidentiality and voluntary participation aspects to the workers. An independent person, trained in ethics, was also introduced to the workers and from whom they obtained consent forms and returned signed consent forms. The completed informed consent forms were kept in a locked cabinet in the administration building until the end of measurements. Subsequently, all forms are kept in the study leader's office in a locked cabinet where they will remain for 10 years. For reporting purposes, data are anonymised using codes.

STUDY SITES

Measurements were carried out at two opencast mining operations, hereafter referred to as site A (latitude: $28^{\circ} 10' 16''$ S; longitude: $16^{\circ} 52' 1''$ E) and site B (latitude: $28^{\circ} 15' 47''$ S; longitude: $16^{\circ} 48' 12''$ E) located within the Karas region in the southernmost part of Namibia.

PARTICIPANTS

Workers in all outdoor occupations were recruited to take part in the study. The outdoor occupations at site A were classified as bedrock, metallurgy, engineering and security officers.

Except for bedrock, the same occupations were found at site B. The bedrock workers prepared the bedrock for blasting and cleared the rocks to create paths for vehicles. Metallurgy workers were responsible for cleaning spills and ensuring that the conveyor belts were running properly, while maintenance work, such as welding, was the responsibility of engineering workers. Security officers were responsible for access control to the mining sites.

MEASUREMENTS

The meteorological variables for the measurement period, namely cloud opacity, precipitation rate and albedo, were obtained from Solcast [10] and the total ozone column obtained from Ozone Measuring Instrument (OMI) [11]. The ultraviolet index (UVI) was calculated as a function of the zenith solar angle (SZA) and total ozone column (TOC) using the equation 1:

$$UVI \sim 12.5 \cos SZA^{2.42} (TOC/300)^{-1.23} \quad \text{Equation 1 [12]}$$

Electronic dosimeters used in this study to measure ambient and personal solar ultraviolet radiation exposure were designed and produced by Professor Martin Allen (University of Canterbury and MacDiarmid Institute for Advanced Materials and Nanotechnology). These dosimeters (Supplement Figure 1) measure erythemally weighted solar ultraviolet radiation exposure with the aid of two types of aluminium gallium nitride (AlGaIn) Schottky photodiodes enclosed within a polytetrafluoroethylene (PTFE) casing, as a sensing unit [13, 14].

Study measurements were done over a four-day period during weekdays in the winter season from 28 June to 4 July 2018 for site A and 6-11 July 2018 for site B. To quantify the amount of solar ultraviolet radiation reaching the ground in the absence of shade (i.e., ambient exposure), two electronic dosimeters were placed on a flat, horizontal surface. Also, workers wore one electronic dosimeter each, placed above clothing on the dorsal wrist of the dominant arm using fabric wristwatch straps for the measurement of personal solar ultraviolet radiation exposure. The dosimeters were set to take measurements at one-minute intervals from 08:00 to 16:00.

For calibration, all electronic dosimeters used in the study were placed next to the Solar Light 501 UV Biometer sensor located on the roof of a building at the South African Weather Services (SAWS) in Irene, Pretoria, South Africa (latitude 25.91° S; longitude 28.21° E; altitude 1524 m). The dosimeters were set to measure solar ultraviolet radiation in counts between 08:00 and 16:00 at one-minute intervals for seven days. We summed the one-minute counts to ten minutes to match the Biometer measurement intervals. The Biometer data in minimal erythemal dose (MED) were converted to the standardised unit of erythemal effective radiation exposure, that is, the standard erythemal dose (SED), where 1 SED = 100 J/m [15]. Equations generated from the dosimeter calibration curves were then used to calculate the SED value equivalent to the electronic dosimeter counts. To remove variability and improve the calibration equations, only data from clear sky days were used in the calculations [13, 16].

Basic descriptive statistics in the form of mean, standard deviation (SD) and range were used in the description of meteorological data, total daily exposure, variations in total daily exposure, exposure by occupation, as well as a percentage of ambient solar ultraviolet radiation exposure. Statistical analyses and visualisation of data were performed in GraphPad Prism version 9.5.0.730 for Windows (GraphPad Software, San Diego, California, USA).

4. RESULTS

Historical satellite meteorological data [10, 11] (Table 1) for the two measurement sites show

clear skies with no rainfall, except at the start of the measurements on 29 June at site A when cloud opacity was at 29% at 08:00, 5.5% at 09:00 and 0% for the rest of the day. Surface reflectivity of 0.19 was observed throughout the measurement period at both sites. The daily mean ultraviolet indices were 2.43 and 2.24 with a maximum of 4.51 and 4.88 at noon for site A and B, respectively.

VARIABLE (UNIT)	SITE A MEAN (RANGE WHERE APPLICABLE)	SITE B MEAN (RANGE WHERE APPLICABLE)
Cloud opacity (%) [10]	0.9 (0–29)	0
Precipitation rate (mm/h) ¹⁰ Surface reflectivity [10]	0	0
Calculated ultraviolet index [12]	0.19	0.19

Table 1 Meteorological Factors During the Study Period.

SITE	SOLAR ULTRAVIOLET RADIATION EXPOSURE MEASUREMENT TYPE	OCCUPATION	VALID MEASUREMENT DAY(S)	TOTAL AND TOTAL MEAN DAILY SOLAR ULTRAVIOLET RADIATION EXPOSURE ± SD (SED)	SOLAR ULTRAVIOLET RADIATION EXPOSURE AS A PERCENTAGE OF AMBIENT (%)
A	Ambient	-	1, 2, 3	10.5 ± 0.7	-
(n = 5)	Worker 1	Bedrock	1, 3	2.7 ± 1.8	25.6 ± 17.1
	Worker 2	Bedrock	1, 2, 3	3.3 ± 1.4	32.1 ± 13.4
	Worker 3	Bedrock	3, 4	1.3 ± 0.0	13.1 ± 0.1
	Worker 4	Metallurgy	3	1.4	13.6
	Worker 5	Engineering	3	1.01	9.5
	<i>Worker average</i>			1.9 ± 1.0	18.8 ± 9.5
B	Ambient	-	2, 3	10.2 ± 1.4	-
(n = 4)	Worker 1	Security	4	3.2	31.6
	Worker 2	Metallurgy	2, 3	7.2 ± 0.6	71.1 ± 6.0
	Worker 3	Metallurgy	2, 3	1.5 ± 0.1	15.3 ± 1.1
	Worker 4	Metallurgy	2	1.8	18.4
	<i>Worker average</i>			3.4 ± 2.6	34.1 ± 25.6

Table 2 The mean total daily solar ultraviolet radiation exposure.

The nine participants whose measurements were valid comprised five workers from the following occupations at site A, namely bedrock ($n = 3$), metallurgy ($n = 1$) and engineering ($n = 1$) and four workers at site B, which were represented by the following occupations, namely security ($n = 1$) and metallurgy ($n = 4$). In terms of gender, there were eight males and one female with an average age of 43 years (22–59 years), who classified themselves as Black Africans (Ramotsehoa *et al.*, 2024 unpublished).

AMBIENT AND PERSONAL SOLAR ULTRAVIOLET RADIATION EXPOSURE DATA

The solar ultraviolet radiation exposure measurements in the form of means and means ± standard deviation (range) are presented in Table 2 and Figure 1 in terms of measurement site, worker and occupation.

The mean daily ambient solar ultraviolet radiation for site A was 10.5 ± 0.7 (9.69-11.07) SED. The ambient solar ultraviolet radiation followed a typical bell shape with levels that peaked between 12:00 and 13:00 (Figure 1a). The mean daily personal exposure for site A was 1.9 ± 1.0 (1.01-3.39) SED (Table 2). The mean total daily solar ultraviolet radiation exposure for bedrock workers ($n = 3$) was 2.5 ± 1.0 (1.39 to 3.39) SED, while the daily solar ultraviolet radiation for the metallurgy worker ($n = 1$) and for the engineering worker ($n = 1$) was 1.4 SED and 1.0 SED, respectively. The corresponding mean daily solar ultraviolet radiation exposure as a percentage of ambient was $18.8 \pm 9.5\%$ (9.5 to 32.1%).

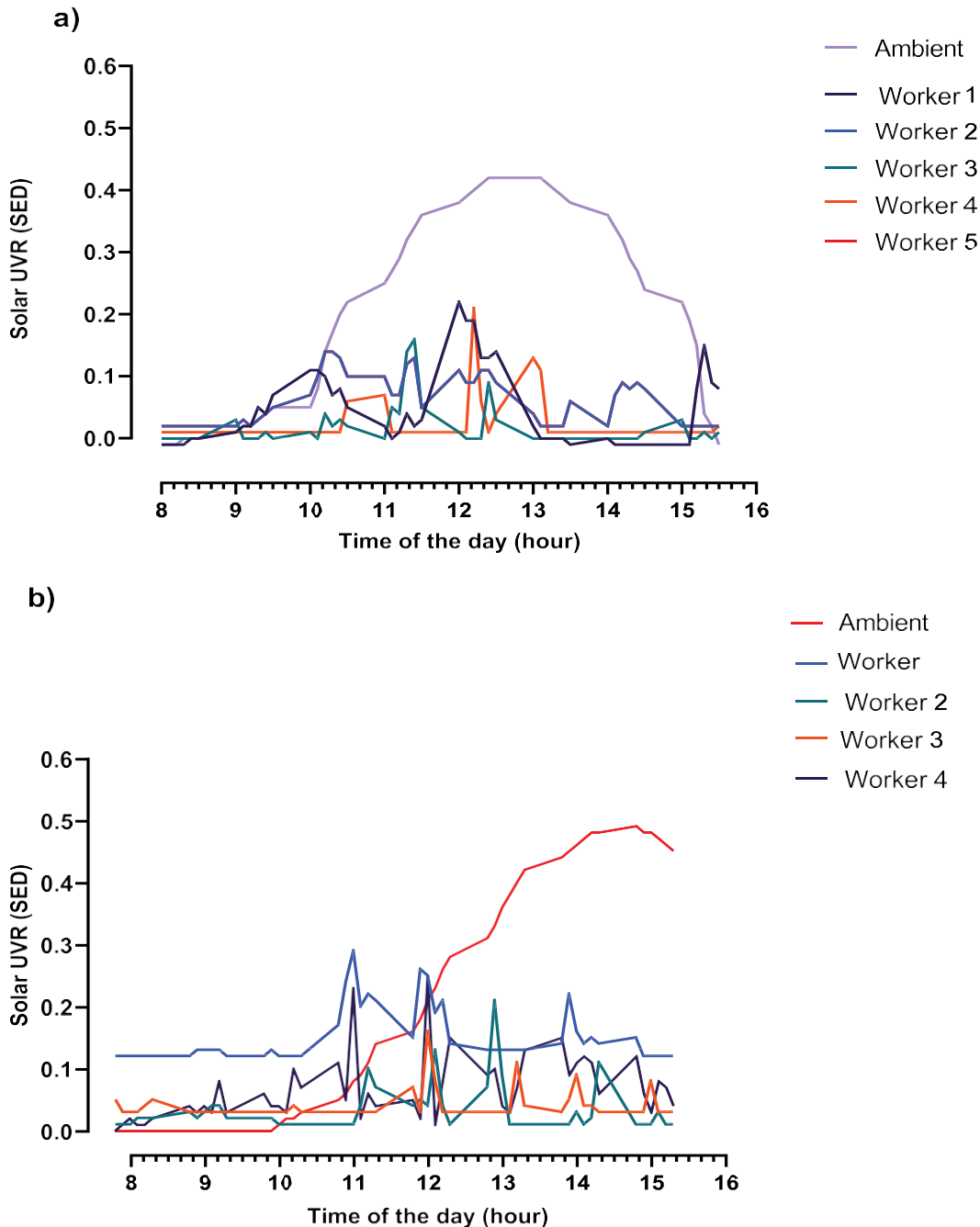


Figure 1 Ambient and personal solar ultraviolet radiation diurnal variations for **(a)**, Site A and **(b)**, Site B.

For site B, the mean daily ambient solar ultraviolet radiation was 10.2 ± 1.4 (3.39-7.28) SED. The ambient solar ultraviolet radiation levels showed an increase from 10:00 and peaked between 14:00 and 15:00 (Figure 1b). The mean daily personal solar ultraviolet radiation exposure for site B was 3.4 ± 2.6 (1.5-7.2) SED, while daily solar ultraviolet radiation exposure for the security officer ($n = 1$) was 3.2 SED and for metallurgy workers ($n = 3$) was 3.5 ± 3.2 (1.8-7.2) SED. The mean daily solar ultraviolet radiation exposure as a percentage of ambient was $34.1 \pm 25.6\%$ (15.34-71.1%).

5. DISCUSSION

To our knowledge, this is the first study in which personal solar ultraviolet radiation exposure

amongst opencast mineworkers in Namibia was measured.

The peak ambient solar ultraviolet radiation level occurred between 12:00 and 13:00 (2.9 SED), in line with solar noon in Namibia at around 12:45, resulting in a characteristic bell-shaped curve for site A. Site B's ambient solar ultraviolet radiation peaked between 14:00 and 15:00 (3.2 SED), a deviation from the expected solar noon which may have been due to the winter season and locality [17].

Of significance for this study was that the mean daily solar ultraviolet radiation exposure for both measurement sites exceeded the International Commission on Non-Ionizing Radiation Protection (ICNIRP) Occupational Exposure Limit (OEL) range of 1.0-1.3 SED, aimed at the prevention of acute health effects of the skin and eyes [15]. More specifically, the guideline is to be treated as a ceiling limit for the eyes and a goal to strive towards for the skin [18]. Similarly, the wintertime mean daily solar ultraviolet radiation exposures that exceeded the ICNIRP-OEL were reported in a study of South African outdoor workers (upper arms, 5.4 SED) (Hadjee, 2020 unpublished data, <https://repository.nwu.ac.za/handle/10394/26476/discover>.) and New Zealand outdoor [19] workers (4.8 SED). Given that these were wintertime exposures, the summertime exposure levels are likely to be higher [20]. Inversely, the mean personal solar ultraviolet radiation exposure measured on the shoulder using polysulphone dosimeters was higher in winter than in summer for Australian teachers [21]. Furthermore, findings from a study conducted by Parisi *et al.* [22] showed an increase of 2.0 SED in the exposure of all participants during winter.

The mean solar ultraviolet radiation exposure as a percentage of ambient in this study was similar to those obtained in one of the pioneering studies by Larko and Diffey [23], while other studies reported lower (Hadjee, 2020 unpublished data, <https://repository.nwu.ac.za/handle/10394/26476/discover>) and higher [24] wintertime mean solar ultraviolet radiation as a percentage of ambient. Diurnal variations observed in personal solar ultraviolet radiation exposures (Supplement File 2) highlighted the importance of other variables that may require further investigation, such as the types of tasks performed, postures assumed and different work areas related to the proportion of the atmosphere (sky) that is not blocked by structures, as well as general human behaviour [18]. Also, the difference in findings from the two measurement sites highlights the importance of measuring outdoor worker exposure to solar ultraviolet radiation [25], even at sites that are within the same country region.

Noteworthy is that the layout in opencast mining sites does not allow for extensive control of environmental factors to protect against excess solar ultraviolet radiation exposure [26], and the only control measure observed at the study sites was shading provided during lunch breaks. This is significant because the combination of clear skies, the noon ultraviolet index in the moderate range (3-5), the high personal solar ultraviolet radiation exposure, the need for protective measures against solar ultraviolet radiation exposure such as seeking shade, covering the exposed skin and application of sunscreen are recommended [27]. Although the workers' risk for developing skin cancer are lower due to their darker skin types, they are not immune to other negative health effects of the skin and eyes [20, 28]. Modenese *et al.* [29] recommends intentional risk evaluation for solar ultraviolet radiation exposure of the eyes and examination of eyes for outdoor workers already exposed, followed by the provision of task-appropriate protection and health surveillance as part of the occupational health services. Additionally, tailor-made, skin phototype-specific health messages, policies and training on sun-safe exposure practices are required [30, 31] for the improvement in the use of and compliance with sun protection measures [32].

6. LIMITATIONS

Failure of the electronic dosimeters to transfer data and battery failure in this study presented a limitation to the measurements similar to those reported by Køster *et al.* [33] for the same type of electronic dosimeters. It is acknowledged that surface reflectivity will influence solar ultraviolet radiation exposure and that the dosimeters used would have been able to record it. However, we did not set out to measure surface reflectivity, and this presents a limitation of the study.

7. CONCLUSION

Study findings demonstrate the need for adequate sun protection for the skin and eyes to include winter since cumulative exposure is an important aspect of outdoor workers' occupational health. The feasibility of producing time-stamped personal solar ultraviolet radiation exposure was

demonstrated.

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10. COMPETING INTERESTS

The authors have no competing interests to declare.

11. ADDITIONAL FILES

The additional files for this article can be found as follows:

- **Supplementary File 1.** Figure 1. DOI: <https://doi.org/10.5334/aogh.4490.s1>.
- **Supplementary File 2.** Ethics approval letters. DOI: <https://doi.org/10.5334/aogh.4490.s2>.

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CHAPTER 4. Article II

Title page

<p>SOLAR ULTRAVIOLET RADIATION EXPOSURE OF MINeworkERS AT SELECTED OPENCAsT MINING OPERATIONS IN NAMIBIA.</p>
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Note: Manuscript for submission to the journal, *Annals of Workers Exposure and Health*

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Abstract

Introduction: There is a lack of information on occupational solar ultraviolet radiation (UVR) exposure of outdoor workers at opencast diamond mining operations in general and during winter. Thus, the aims of the study were to establish the constitutive (photoprotected) and facultative (photoexposed) skin colour of outdoor opencast mineworkers in Namibia, to quantify their exposure to solar ultraviolet radiation on different body positions, and to establish the effectiveness of their clothing as a protective measure against solar ultraviolet radiation exposure.

Methods: Skin colour expressed as ITA, was measured on the volar upper arm and dorsal forearm using Colorimeter CL 400 (Courage + Khazaka Electronics, GmbH, Germany). Using polysulphone dosimeter badges, ambient and personal (head, neck, shoulder above and under clothing and wrist) solar UVR exposure were measured over four days at two opencast diamond mining operations in Namibia during winter. Thirty-eight workers from bedrock, engineering, metallurgy, and security job categories participated in the study.

Results and conclusion: Workers' constitutive skin phototype were classified into intermediate to black phototypes (groups III to VI) while the highest percentage (73%) of workers' facultative skin phototypes were classified into black phototypes (group VI). This indicated a higher degree of natural photoprotection. The mean daily solar UVR exposure doses received on all body positions (2.07 – 3.69 SED) and job categories (2.00 – 3.11 SED) exceeded the International Commission on Non-Ionizing Radiation Protection (ICNIRP) solar UVR exposure guideline upper limit of 1.3 SED over an 8-hour period with the head receiving the highest mean daily exposure. Overall, the different body positions received high mean daily percentages of ambient with the highest (214.70%) received on the heads of engineering workers. The clothing worn by workers offered adequate solar UVR protection for the shoulder. Outdoor workers at the two opencast diamond mining operations were at the risk of overexposure to solar UVR and the related negative health effects.

Introduction

The higher exposure to solar ultraviolet radiation (UVR), a Group I carcinogen, together with the inability to eliminate the source nor avoid spending time outside, place outdoor workers at an even higher risk of developing negative health effects associated with solar UVR (ICNIRP, 2010). Thus, solar ultraviolet radiation (UVR) presents a major risk to the occupational health and safety of outdoor workers, including those in opencast mining operations (Milon *et al.*, 2014; ILO, 2018). The negative effects of solar UVR on the skin include erythema or sunburn, local and systemic immune impairment, aging, keratinocyte carcinoma [non-melanoma skin cancer (NMSC)], and melanoma (Hart *et al.*, 2019; Neale *et al.*, 2023). The risk of developing skin cancer for outdoor workers increases (Kovačić *et al.*, 2020) with 65 to 90% of reported skin cancers attributable to solar UVR exposure (Wittlich, 2022) although underreporting remains a challenge even in Europe (Gobba *et al.*, 2019). In addition to the skin, negative effects on the eyes such as cortical cataract and pterygium are associated with solar UVR exposure (ICNIRP, 2010).

Personal exposure to solar UVR is determined by personal attributes and behaviours including avoidance of peak period exposure, and the use of sun protective measures such as hats, sunscreen, sunglasses, shade and clothing (Vernez *et al.*, 2015; Wainwright *et al.*, 2017). In terms of personal attributes, the types and amount of melanin in the skin determine the inherent differences observed in constitutive skin colour (photoprotected) within the different ethnicities, and the response of the skin to solar UVR (Del Bino and Bernerd, 2013). Upon exposure to solar UVR, photoexposed skin areas become darker as a way of adaptation, and this presents as the facultative skin colour (Jablonski and Chaplin, 2010). The higher amount of melanin in darker skin types reduces their risk to solar UVR induced skin cancer (Krutmann and Piquero-Casals, 2023), yet they remain susceptible to the different solar UVR related eye conditions (Passeron *et al.*, 2021) and skin conditions such as post-inflammatory hyperpigmentation (Markiewicz *et al.*, 2022). This is of importance for Namibia since Black Africans make up to 87% of the Namibian population (Namibia Statistics Agency, 2024).

Avoidance of exposure during peak hours is mostly not a viable preventive measure at work since outdoor workers are not able to schedule their working hours, nor can

they choose to work under a shaded structure. This situation increases the reliance on personal protective equipment (PPE) to ensure that highly exposed body positions such as the upper body are effectively covered/protected (Zink *et al.*, 2017; Merin *et al.*, 2022; Ruales *et al.*, 2022). Protection against solar UVR exposure is largely ignored when compared to other environmental hazards. This lack of focus is due to the absence of country specific exposure limits on a global and African level, affecting compliance (Grandahl *et al.*, 2018; John *et al.*, 2021). However, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) has created a recommended exposure guideline of 30 J/m² (Joules per metre squared) which is equivalent to 1.0 - 1.3 SED over an 8-hour period (standard erythemal dose) where 100 J/m² equals to 1 SED weighted against the erythemal effectiveness curve. The exposure guideline is meant for acute effects of the skin and eyes to solar UVR exposure and is not appropriate for chronic exposure (CEN, 2008; ICNIRP, 2010).

With the need to convince a worker about protection against exposure, reliable measurement of occupational solar UVR exposure using personal dosimetry is considered necessary (ICNIRP, 2010; John *et al.*, 2016; Wainwright *et al.*, 2017; Kovačić *et al.*, 2020). Personal exposure measurements also assist with the identification of at-risk workers (Kovačić *et al.*, 2020). The solar UVR exposure of workers in outdoor occupations such as construction and farming has received attention mostly in European countries, Australasia and Canada (Gies and Wright, 2003; Thieden *et al.*, 2005; Hammond *et al.*, 2009; Moldovan *et al.*, 2020). In Africa, however, far fewer studies have been carried out (Makgabutlane and Wright, 2015; Nkogotse *et al.*, 2019; Linde *et al.*, 2022) even though outdoor workers experienced high solar UVR exposure throughout the year (Makgabutlane and Wright, 2015).

Solar UVR exposure measurements during summer with dosimeters attached on the wrist are well documented even though higher exposure is experienced on the upper body positions (Milon *et al.*, 2007; Reeder *et al.*, 2013; Vernez *et al.*, 2015). Interestingly, winter solar UVR exposure dose has been shown to be higher in many cases than summer and it also exceeded the ICNIRP exposure guideline in some studies (Kimlin *et al.*, 2006; Gies *et al.*, 2014; Downs *et al.*, 2019). It was also estimated that outdoor workers receive 42% of ambient solar UVR during winter which contributes to cumulative solar UVR exposure which may put their health at risk (Neale

et al., 2010). To date, little information is available on the solar UVR exposure of outdoor mineworkers in two opencast diamond operation in Namibia. Thus, the aims of the study were as follows: 1) to establish the constitutive and facultative skin colour of the workers, 2) to quantify their personal exposure to solar UVR at different body positions, and 3) to establish the effectiveness of clothing as a protective measure against solar UVR exposure.

Methods

Ethical clearance for this study was granted by the North-West University Health Research Ethics Committee (NWU-00031-17-A1) and Namibia Ministry of Health and Social Services (17/3/3 CR). The study measurements were carried out in winter over four days during working hours at two opencast diamond mining operations in the Karas region of Namibia, hereafter referred to as Site A (Latitude: 28°10'16"S; Longitude: 16°52'1"E) and Site B (Latitude: 28°15'47"S; Longitude: 16°48'12"E). Workers who gave their informed consent participated in the study.

In the mining operations, outdoor workers responsible for the preparation of the bedrock for blasting and clearing of rocks for creation of paths to be used by vehicles, were classified under the job category, bedrock. Metallurgy workers were responsible for cleaning spillages and ensuring that conveyer belts were running properly, while engineering workers carried out any maintenance work that included welding. Security workers were responsible for access control to the mining sites.

Skin colour measurements

The skin colour of the workers was measured with a calibrated Colorimeter CL 400 (Courage + Khazaka Electronics, GmbH, Germany) using a parameter known as individual typology angle (ITA). The individual typology angle is calculated (using formula 1) from the International Commission on Illumination (CIE) $L^*a^*b^*$ colour system (Del Bino and Berend, 2013). L^* represents perceptual lightness, while a^* and b^* correspond to the four distinctive colours perceived by humans: red, green, blue, and yellow.

$$ITA = \tan^{-1} \frac{L^* - 50}{b^*} \quad (1)$$

ITA was measured on the volar upper arm for constitutive skin phototype and dorsal forearm for facultative skin phototype. Workers were asked to wipe the skin measurement areas with hypoallergenic, alcohol-free wipes as they entered the venue. Measurements were taken in triplicate after 20 minutes of acclimation at room temperature. The skin phototypes were classified according to the following guidelines prescribed by Del Bino (2006):

Very light (I) > 55° > Light (II) > 41 ° > Intermediate (III) > 28° > Tan (IV) > 10° > Brown (V) > -30° > Dark (VI) (2)

Measurements of solar personal and ambient UVR exposure

Polysulphone dosimeters (PSF badges) purchased from the Manchester University, United Kingdom were used to measure ambient solar UVR and personal solar UVR exposure. The PSF badge consists of a 15 x 10 mm plastic film mounted on a cardboard edging. The film underwent photo-degradation that changes its optical absorbance when exposed to solar UVR. The change was then quantified with a UV/V ultraviolet-visible light spectrophotometer (Model: SP-UV1000, DLAB Scientific Company, China) at a wavelength of 330 nm. When a two-week delay in the reading of post absorbance within the prescribed 24 hours post exposure occurred, a 5% correction factor was subtracted from the absorbance to offset the effect of the dark reaction (Geiss *et al.*, 2003).

For calibration, 48 PSF badges with pre-determined absorbance, were placed next to a calibrated UV Biometer that measures biologically effective irradiance in minimal erythemal dose (MED), located at the offices of the South African Weather Services, Irene, Pretoria, South Africa. One PSF badge was removed every 10 minutes and post exposure absorbance measured with a UV-visible light spectrophotometer at 330 nm. The MED was then converted to J/m^2 (1 MED = 210 Joule/m^2). To convert the change in absorbance to solar UVR equivalence, the calibration equation was obtained from the calibration curve created with the change in absorbance plotted against the irradiance measured with the broadband solar UVR instrument in Joule/m^2 (J/m^2) (Geiss *et al.*, 2003). The solar UVR doses were then converted to standard erythemal dose (SED) where 1 SED = 100 J/m^2 of erythemal effective UVR exposure spectrally weighted with the erythemal action spectrum (CEN, 2008).

On each day of the study, the daily ambient solar UVR was measured using two PSF badges that were placed on a horizontal surface away from structures that may produce shading. Workers wore new PSF badges each day on the top of the head (attached to the hard hat), the back of the neck (attached to collar of the coverall), horizontally on the shoulder, and the wrist using non-allergenic surgical tape. Adjacent to the PSF badge placed above the coveralls on the shoulder, another badge was placed under coveralls to establish the effectiveness of solar UVR protection afforded by the clothing worn.

Data analysis

Data analyses were conducted using IBM SPSS (Version 29) and illustrated using GraphPad (Version 10.3.1(509)). The non-normal distribution of the ITA and solar UVR data necessitated the use of non-parametric statistical analyses. The Wilcoxon Signed rank tests was used to compare the ITA within and between the constitutive and facultative skin phototypes. The Kruskal-Wallis' test with a Bonferroni post-hoc correction for multiple comparisons was used to compare exposures between body positions, between job categories, and between body positions within the job categories. The practical significance of the differences was also tested using Cohen's *d* effect size (Sullivan and Feinn, 2012). To determine the effectiveness of clothing worn by workers, measurements taken above and under clothing on the shoulder were compared using the Wilcoxon Signed rank test. For all statistical analyses, the differences were regarded as statistically significant when $p \leq 0.05$.

The means, standard deviation (SD), and range (minimum and maximum) were used in the reporting of ITA values, personal solar UVR exposures and the corresponding solar UVR exposure as percentage of ambient solar UVR to make comparison to previous studies possible. For comparisons of solar UVR exposure data, data from the security workers was excluded.

3. Results

In total, 38 workers participated in the study of which nine were bedrock workers, 19 were engineering workers, nine were metallurgy workers, and one was a security worker.

Skin colour

The constitutive skin colours of the workers were classified into skin phototypes III (intermediate) to phototype VI (black) with ITA ranging between -30.33° and 33.33° (Table 1). Forty nine percent of workers' constitutive skin phototypes were in skin phototype V (brown) followed by 33% in skin phototype VI (black). Facultative skin phototypes on the other hand had more workers (73%) classified into skin phototype VI (black) and the ITA that ranged from -55.33° to 19.00° . Comparisons of the ITA indicated statistically significant differences within phototypes V, VI and combined (total) ITA of both constitutive and facultative skin phototypes. Statistically significant differences were also found between the combined ITA of constitutive and facultative skin types when evaluated using the Wilcoxon signed rank test ($p = 0.0011$).

Table 1. Skin phototype classification based on ITA.

	Skin phototypes	% of workers	Mean ITA \pm SD ($^{\circ}$)	Minimum ITA ($^{\circ}$)	Maximum ITA ($^{\circ}$)
Constitutive skin colour	III (intermediate)	9	35.44 ± 3.37	33.33	39.33
	IV (light brown)	9	20.33 ± 6.65	13.00	26.00
	V (dark brown)	49	$-18.29 \pm 6.29^{a,b}$	-29.00	-5.33
	VI (black)	33	$-36.7 \pm 5.84^{c,d}$	-45.67	-30.33
	Combined (Total)	100	-16.03 ± 23.55^e	-45.67	39.33
Facultative skin colour	IV (light brown)	6	15.67 ± 4.76	12.33	19.00
	V (dark brown)	21	$-15.00 \pm 11.42^{b,f}$	-28.67	2.67
	VI (black)	73	$-40.62 \pm 7.973^{d,g}$	-55.33	-30.33
	Combined (Total)	100	$-31.78 \pm 18.22^{e,h}$	-55.33	19.00

^a $p < 0.0001$; ^b $p < 0.001$; ^c $p = 0.001$; ^d $p = 0.0001$; ^e $p = 0.0011$; ^f $p = 0.0031$; ^g $p < 0.0001$; ^h $p < 0.001$. Note: a, c, f, g, and h denote statistical differences within the phototype

Mean daily ambient solar UVR

The mean daily ambient solar UVR for Site A and Site B were 8.02 ± 2.21 SED and 12.31 ± 1.06 SED respectively. The mean daily solar UVR exposure and mean daily ambient solar UVR values were used to calculate exposure as percentage of ambient described in this section.

Personal solar UVR exposure and percentage of ambient by body position

Data presented in Figure 1 showed statistically significant differences in the solar UVR exposure received on the combined body positions ($p \leq 0.05$). More specifically, the mean daily solar UVR exposure received on the neck (2.16 ± 1.99 SED) and the wrist

(2.43 ± 1.22 SED) were both statistically significantly lower than the mean dose received on the head (3.69 ± 3.48 SED). The differences were moderately practically significant for head and neck ($d = 0.47$), and head and wrist ($d = 0.39$). Furthermore, the mean daily solar UVR exposures received on all body positions and combined body positions exceeded the ICNIRP exposure guideline upper limit of 1.3 SED over an 8-hour period. Both the highest (received on the head) and lowest (received on the neck) mean daily solar UVR exposures exceeded the upper limit of the ICNIRP exposure guideline by 95.98% and 45.69%, respectively.

The Kruskal-Wallis test with Bonferroni post-hoc correction of exposure as percentage of ambient solar UVR for combined body position showed that the statistically significant differences. The mean daily exposures as percentage of ambient (Table 2) for the neck ($23.15 \pm 26.97\%$) and wrist ($25.53 \pm 25.58\%$), were both statistically significantly different to that received on the head ($41.18 \pm 39.57\%$). The highest and lowest maximum exposures as percentage of ambient solar UVR were 214.70% for the head and 124.70% for the shoulder, respectively.

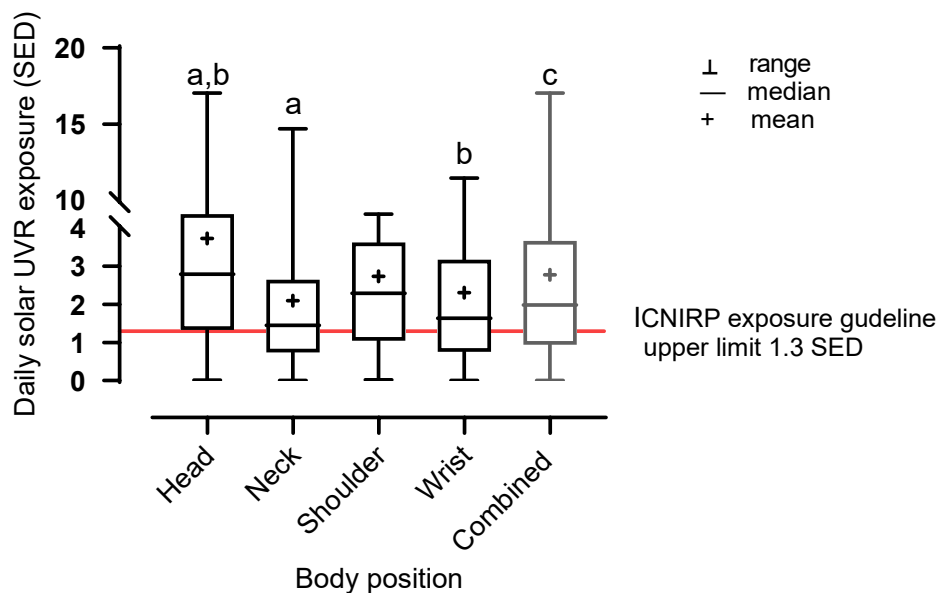


Figure 1. Daily solar UVR exposure by body position with ICNIRP exposure guideline upper limit indicated by a red line. Statistical significances were established using the Kruskal-Wallis' test with Bonferroni post-hoc correction a) $p < 0.0001$, b) $p = 0.002$, c) $p < 0.0001$.

Table 2. Daily personal solar UVR exposure as percentage of ambient presented by job category and body positions [expressed as mean \pm SD (in 1st row) and range (in 2nd row)].

Body Position	Bedrock (n=9)	Engineering (n=19)	Metallurgy (n=9)	Combined body position
Head	37.57 \pm 41.82 0.20 - 189.93	43.49 \pm 43.70 0.34 - 214.69	39.82 \pm 23.97 ^a 0.34 - 86.04	41.18 \pm 39.57 ^{b,c} 0.02 - 214.70
Neck	17.13 \pm 7.45 5.55-29.55	28.84 \pm 35.43 0.78 - 185.02	17.47 \pm 14.64 ^a 0.03 - 55.04	23.15 \pm 26.97 ^b 0.03 - 185.02
Shoulder	20.06 \pm 9.97 4.24 - 33.61	40.13 \pm 35.82 0.29 - 124.70	31.39 \pm 26.29 0.487 - 91.39	30.76 \pm 28.05 0.29 - 124.70
Wrist	20.96 \pm 25.81 0.08 - 107.58	27.17 \pm 26.11 0.29 - 144.31	27.51 \pm 25.66 0.39 - 122.99	25.53 \pm 25.58 ^c 0.08 - 144.31
Combined job category	25.18 \pm 29.0 ^d 0.08 - 189.93	34.46 \pm 36.36 ^d 0.29 - 214.69	29.15 \pm 23.88 0.03 - 122.99	

Statistical significances were established using the Kruskal-Wallis' test with Bonferroni post-hoc correction. ^ap=0.003, ^bp=0.000, ^cp=0.001, ^dp=0.040.

Personal mean daily solar UVR exposure and exposure as percentage of ambient solar UVR by job categories

Overall, the Kruskal-Wallis' test with Bonferroni post-hoc correction indicated that the mean daily exposures between the job categories (Figure 2) were statistically significantly different ($p < 0.0001$). More specifically, the mean daily exposures for Engineering workers (3.11 ± 3.07 SED) and Metallurgy workers (2.88 ± 2.41 SED) were both statistically significantly different to that received by Bedrock workers (2.00 ± 2.31 SED). The statistically significant differences found between solar UVR exposures of Bedrock and Engineering workers ($d = 0.36$), and Bedrock and Metallurgy workers were moderately practically significant ($d = 0.37$). The mean daily solar UVR exposure received by all job categories exceeded the ICNIRP exposure guideline upper limit of 1.3 SED over an 8-hour period as depicted in Figure 2.

The testing of the mean daily solar UVR exposure percentage of ambient solar UVR of the combined job categories (Table 2) through the Kruskal-Wallis's test and Bonferroni post-hoc correction produced a statistically significantly difference ($p = 0.040$). Further analysis of exposure as percentage of ambient solar UVR within job categories using the same tests showed statistically significant differences between Bedrock workers ($25.18 \pm 29.07\%$) and Engineering workers ($34.46 \pm 36.36\%$). The

effect sizes of $d = 0.30$ between Bedrock and Engineering workers indicated that the statistically significant differences were both moderately practically significant.

Personal solar UVR exposure and percentage of ambient solar UVR by body positions within job categories

The Kruskal-Wallis test with Bonferroni post-hoc correction produced statistically significant differences between the mean daily solar UVR dose received on the head (3.79 ± 2.76 SED) and that of the neck (1.72 ± 1.33 SED) within the Metallurgy job category (Figure 2). These differences also produced a larger effect size ($d = 0.75$). The rest of the body positions within all the body positions produced small to moderate effect sizes. Of importance was that the mean daily solar UVR exposures received within the different job categories exceeded the ICNIRP exposure guideline upper limit of 1.3 SED over an 8-hour period as shown in Figure 2.

Similarly, the differences between the head ($39.82 \pm 23.97\%$) and the neck ($17.47 \pm 14.64\%$) of Metallurgy workers in the mean daily percentage of ambient solar UVR were statistically different (Table 2).

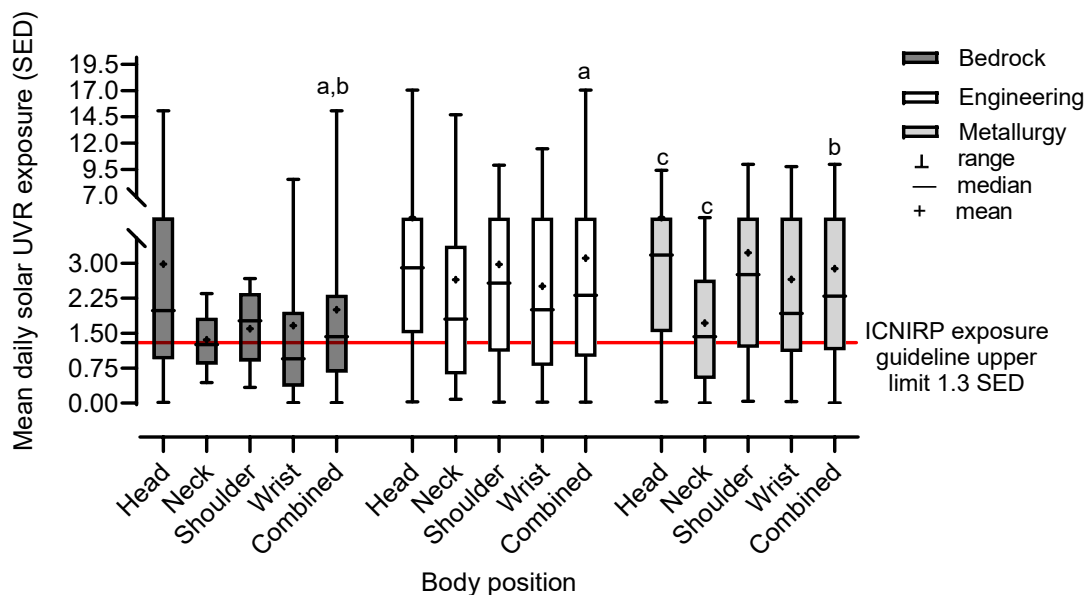


Figure 2. Daily solar UVR exposure by body position within job categories with ICNIRP exposure guideline upper limit indicated by red line. Statistical significances were established using the Kruskal-Wallis' test with Bonferroni post-hoc correction a) $p = 0.0001$, b) $p = 0.003$, c) $p = 0.019$.

Clothing protection against solar UVR

The Wilcoxon signed rank test produced statistically significant differences between the combined daily solar UVR exposure received above clothing (2.73 ± 2.26 SED) and under clothing (0.08 ± 0.27 SED) (Figure 3). The statistically significant difference also produced a large effect size ($d = 1.68$). The clothing effectively blocks 97.1% of the solar UVR from reaching the skin on the shoulder. Statistically significant differences were also found within all the job categories when assessed using the Wilcoxon signed rank test. Regarding solar UVR exposure as percentage of ambient solar UVR, statistically significant differences were found between combined (for the three job categories) above clothing and below clothing and within all job categories when tested using the Wilcoxon signed rank test. The solar UVR exposure as percentage of ambient solar UVR received on the shoulder ranged from 0.29 to 124.7%.

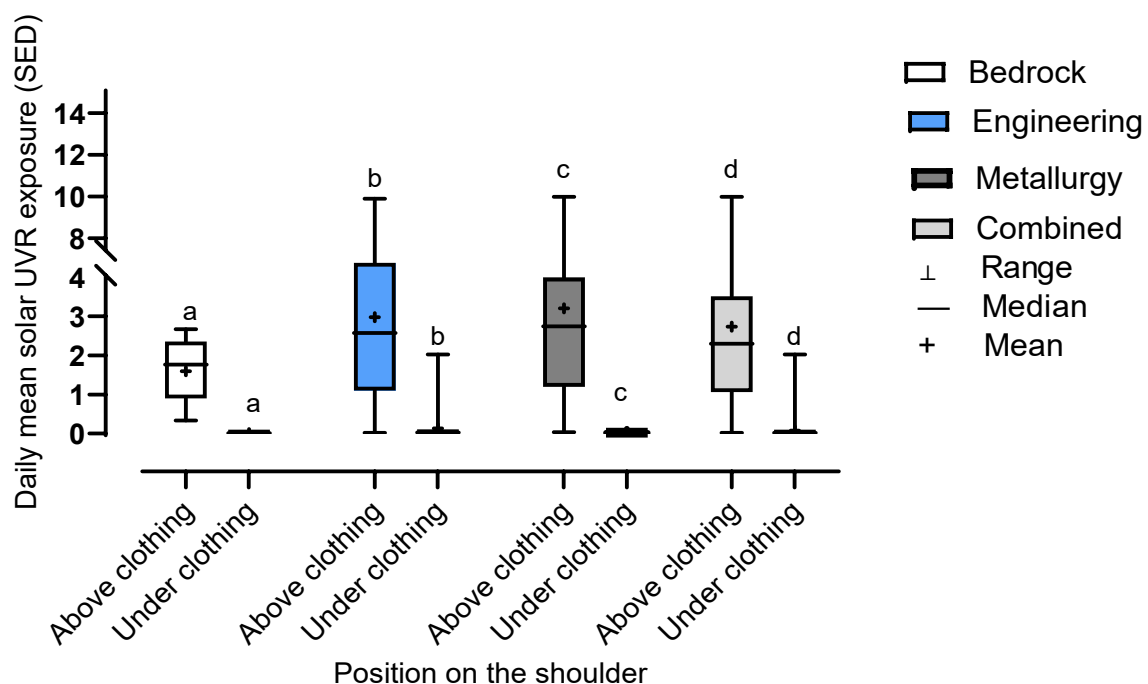


Figure 3. The daily mean solar UVR exposure measured above and under clothing. Statistical significance differences were established using Wilcoxon Signed rank test. a) $p < 0.0001$, b) $p < 0.0001$, c) $p < 0.0001$, d) $p < 0.0001$.

Discussion

To our knowledge, this is the first study to objectively measure differences between constitutive and facultative skin colour and quantify personal exposure of opencast mineworkers to solar UVR in Africa with consideration of differences in exposed body

positions. The findings of this study (Table 1, constitutive skin colour) showed that 91% of the workers were of darker skin phototypes (IV-VI). The solar UVR exposure of outdoor workers on all body positions and overall job categories exceeded the ICNIRP exposure guideline upper limit. The workers also received high percentage of ambient solar UVR on all body positions. The clothing was found to be effective in blocking the solar UVR from reaching the skin as measured on the shoulders.

The higher percentages of workers' constitutive and facultative skin phototype classified as brown to dark (V to VI) was consistent with 87% of Namibian population demography that was classified as Black African (Namibia Statistics Agency, 2024). Pigment darkening in workers who receive regular and significantly higher solar UVR exposure than other workers (Gies and Wright, 2003) is an important indicator of adaptation to longer-term solar UVR exposure beyond just sunburn (ICNIRP, 2010). This accounted for the significant differences found in ITA between photoprotected and photoexposed skin phototypes. People with darker skin encompass diverse ethnicities that exhibit a wide variety of skin colours (Krutmann *et al.*, 2023). The combination of melanin, carotenoids, haemoglobin and oxyhaemoglobin were responsible for variations in darker skin phototypes (Naik and Farrukh, 2022) bringing about the significant differences observed within brown (phototype V) and black (phototype VI) skin phototypes in this study.

The photoprotection offered by the higher melanin in darker skin types and associated lower risk for skin cancer development (Munjal and Ferguson, 2020), has resulted in solar UVR exposure studies placing more focus on individuals with lighter skin types (Krutmann *et al.*, 2023). However, individuals with darker skin types are prone to hyperpigmentation disorders such as melasma which results in negative emotional and psychological effects on affected individuals (Passeron *et al.*, 2021). In addition, these workers with darker skin types, are equally susceptible to the effects of high solar UVR exposure above the ICNIRP exposure guideline on the eyes and the immune system (Agbai *et al.*, 2014; Fajuyigbe and Young, 2016; Schmalwieser *et al.*, 2021). Of significance for solar UVR exposure is that the immunosuppression occurs at levels lower than usually known to cause sunburn, albeit that sunburn is a factor that is likely to be missed on darker skin (Poon *et al.*, 2005). Because solar UVR impairs local and systemic immunity, it may contribute to tumorigenesis (Liu *et al.*,

2015; Sharma and Rudra, 2018). Thus, country-specific interventions directed at demonstrating the link between solar UVR exposure and hyperpigmentation, aging, and cortical cataracts, with messages that are culturally sensitive (Agbai *et al.*, 2014), are likely to be more effective than those that are directed mainly at skin cancer prevention for the workers in this study (Farrar *et al.*, 2013; Maymone *et al.*, 2017). More specifically, cataract cases are reported to be increasing steadily in Africa (Schmalwieser *et al.*, 2021).

Of the many studies that have evaluated the exposure of outdoor workers to solar UVR exposure in different countries and occupations, the focus has been on summer and spring (Grandahl *et al.*, 2018; Modenese *et al.*, 2018; Peters *et al.*, 2019). Nonetheless, the levels of solar UVR exposure and exposure as a percentage of ambient solar UVR in this study not only exceeded the ICNIRP exposure guideline, but they were also higher than both winter and summer doses found in other similar studies. For example, in Australia, classroom teachers received a mean solar UVR exposure of 0.91 SED in winter which was higher than their summer exposure of 0.63 SED (Downs *et al.*, 2019). Teachers working in tropical regions experience a different sense of thermal comfort during the north Australian winter with conditions that are much milder compared to summer, characterised by lower humidity and peak temperatures that rarely surpass 30°C. Additionally, changes in cloud cover, with more clouds in summer and fewer in the drier winter, might account for some of the differences noted in solar exposure between the winter and summer groups in that study (Downs *et al.*, 2019). Also, high maximum solar UVR exposure was received by outdoor workers in building and construction, and farmers received 0.2 to 4.03 SED and 0 to 10 SED, respectively, in another study during winter (Gies *et al.*, 2014).

In agreement with the winter solar UVR exposure of Australian cyclists (Kimlin *et al.*, 2006), the head received the highest exposure in all the job categories. The hierarchy of solar UVR exposure on the body position in our study (head/shoulder > wrist > neck) based on mean exposure was similar to that of another study carried out in South Africa in late winter although the wrist was excluded in that study (Wright *et al.*, 2004). However, the exposure doses received on the head, shoulder and neck in a study by Wright *et al.* (2004) were lower than in this study. Italian farmers received the highest maximum exposure on the neck of 2.33 SED during spring and summer (Nardini *et*

al., 2014) which was lower than the maximum of 14.69 SED measured in this study for the neck during winter. The mean daily solar UVR exposure received on the wrist (2.43 ± 2.23 SED) agrees with the mean daily exposure measured on the wrist with electronic dosimeters (2.60 ± 1.92 SED). The finding contrasts with the reported differences of between 20% and 30% between these two dosimeters, where exposure was exaggerated by the PSF dosimeters (Strehl *et al.*, 2021).

Although the ambient solar UVR is estimated to be three times higher in summer than in winter, outdoor workers receive twice more of the percentage of ambient solar UVR in winter (Neale *et al.*, 2010). Similarly, Sun *et al.* (2014) reported mean exposure as a percentage of ambient solar UVR of 1 to 4% in summer and 7% in winter. An overall mean exposure as a percentage of ambient solar UVR for the different occupations of 13.5% was calculated in another study (Gies *et al.*, 2014). In this study, the head received a lower mean percentage of ambient solar UVR ($41.18 \pm 39.57\%$) than the 100% reported in other studies (Kimlin *et al.*, 1997; Wright *et al.*, 2004). The highest maximum percentage of ambient was measured on the head (214.70%), while the percentage of ambient for the neck (185.02%) was higher than that received by farmworkers (117.8%) in Italy (Nardini *et al.*, 2014) and the 74.4% measured in another South African study (Wright *et al.*, 2004).

The high maximum exposure as percentage of ambient solar UVR found in this study and previous studies, support the notion that outdoor workers receive a considerable amount of their yearly solar UVR exposure dose during winter (Dobbinson *et al.*, 2008), motivating the inclusion of winter measurements in solar UVR exposure measurements. Accordingly, the workplace needs to review messages around sun protection that are only directed at summer exposure (Dobbinson *et al.*, 2008). This aspect is even more relevant for African countries such as Namibia where mild winter temperatures may allow for more time being spent outdoors (Dobbinson *et al.*, 2008). Additionally, high temperatures that are commonplace in Africa even during winter, may hamper the repair of DNA damage caused by solar UVR exposure (Freedman *et al.*, 2015) similar to those caused by climate change (Bernhard *et al.*, 2023).

Occupational exposure limits prescribed in the occupational health legislation are important for the protection of workers and the implementation of control measures

(Ruales *et al.*, 2022). In African countries, the lack of legislation related to solar UVR exposure (Tertsea *et al.*, 2013; Lucas *et al.*, 2016; Schmalwieser *et al.*, 2021), deepens the lack of knowledge of solar UVR as an occupational hazard observed in other studies (Reeder *et al.*, 2013; Wright and Norval, 2021; Symanzik *et al.*, 2023). Also, the current ICNIRP exposure guideline works well for acute exposure but falls short of evaluating chronic exposure to solar UVR (Modenese *et al.*, 2018) and is likely to be reached within minutes of exposure due to the high ambient solar UVR in African countries (Milon *et al.*, 2007; Wright *et al.*, 2011).

The clothing worn by workers in this study was shown to offer adequate protection on the shoulder. Positive aspects of the personal protective equipment (PPE) program in the mining operations studied in Namibia were the hard hats and long-sleeved coveralls that offer protection for the head, shoulders, and to some extent the wrists. This is significant since the exposure of the head exceeded the ICNIRP exposure guideline by 95.98%, highlighting the importance of protection for the head and upper body positions throughout the year as they are known to receive higher solar UVR exposure (Vernez *et al.*, 2015). The workers at the two mining operations would benefit from implementation of additional photoprotective measures such as the introduction of a flap to the hard hats for neck protection, use of sunscreen for bare skin, and the wearing of sunglasses (Gies, 2007; Ruales *et al.*, 2022). Also, the evaluation of compliance in the use of protective methods at open cast mining operations under study are required because the lower perceived risk of sunburn and skin cancer among workers with darker skin types is likely to reduce compliance (Hammond *et al.*, 2008; Liu *et al.*, 2016; Maymone *et al.*, 2017). Moreover, it has been shown that workers perceived workplace support as a factor that may lead to an increase in the use of sun protection (Hammond *et al.*, 2008) in addition to training (Reeder *et al.*, 2013). Although the level of knowledge of solar UVR as an occupational hazard was not part of this study, farmers in Africa and car guards in South Africa were found to lack the education necessary to protect themselves against solar UVR exposure (Liu *et al.*, 2016; Nkogatse *et al.*, 2019).

Conclusion

Overall, the high exposure received on the different body positions indicated that the workers in this study were at the risk of developing the negative health effects caused

by solar UVR, even with increased natural photoprotection. Job category and body positions in addition to the wrist played significant roles in providing a clearer picture of solar UVR exposure patterns. Clothing was found to offer adequate protection on the shoulder and workers would benefit from additional photoprotective measures for the neck, exposed skin areas, and eyes.

Declaration of conflict of interest

The authors have no conflict of interest to declare.

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What is important about this paper:

To our knowledge this is the first study to establish the skin phototypes of opencast mineworkers along with the evaluation of personal solar UVR exposure by different body positions and effectiveness of photoprotective of clothing in Africa. Skin adaptation through pigmentation was shown through statistically significant differences between the ITA measured on photoexposed and photoprotected skin. The mean winter solar UVR exposure that exceeded the upper limit ICNIRP exposure guideline on different body positions in our study, brings the need for inclusion of photoprotection during seasons other than summer or spring into focus.

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CHAPTER 5. ARTICLE III

Title page

SOLAR ULTRAVIOLET RADIATION-RELATED KNOWLEDGE, ATTITUDES, AND BEHAVIOURS OF OPENCAST MINeworkERS IN NAMIBIA
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The author guidelines for this journal are given in supplement A.

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Research Foundation.

Abstract

Aim: The aim of the study was to evaluate the knowledge, attitudes, and behaviours related to solar UVR exposure of mineworkers at two opencast mining operations in Namibia.

Methods: Data were collected from 36 workers using self-completed questionnaires. Fisher's exact tests were used to determine relations between knowledge, attitude, and behaviours scores and participant's characteristics.

Results and discussion: Eighty eight percent of participating workers were males with most being of darker skin types. In total, 65% of the workers stated that it is good to spend time in the sun, and 60% did not know what ultraviolet radiation index (UVI) is. The use, reapplication, and knowledge of sun protection factor (SPF) of sunscreen were poor, and only 30% of workers always wore sunglasses. The standard workplace issued hard hats and coveralls with long sleeves and long trousers, were the protective measures of choice for head and body. No correlations were found between knowledge, attitude, and behaviour scores. Individual knowledge, attitude, and behaviour scores were not statistically significantly associated with sociodemographic characteristics. The level of education had a statistically significant association with combined knowledge, attitude, and behaviours scores.

Conclusion: The level of education was a positive predictor of having adequate knowledge, positive attitudes, and proper use of photoprotective measures. Workers were adequately protected by the provided clothing. Tailoring sun-safety education and training for the workers with different skin sensitivities and levels of education, provision of sunscreen and UV protective goggles at the workplace, may improve sun-safety knowledge, attitudes, and behaviour.

Keywords: sun safety, photoprotective clothing, sunscreen, ultraviolet protective goggles, outdoor workers.

Word count: 3519

Introduction

Exposure to adequate amounts of UVB waveband in solar UVR has health benefits that include, among others, the production of vitamin D, while inadequate and excessive exposure causes negative health effects (Diffey, 2006; Mead, 2008). Erythema, photoaging, pigmentation-related disorders, immunosuppression, eye conditions, and skin cancer are among the adverse health effects associated with excessive exposure to solar UVR (Passeron *et al.*, 2021; Schmalwieser *et al.*, 2021). Thus, outdoor workers are vulnerable to regular and significantly high exposure to solar UVR and associated negative health effects due to extended periods of time spent outside as they conduct daily work activities (Schmalwieser *et al.*, 2010; Pinault and Fioletov, 2017).

To reduce exposure to solar UVR, and prevent associated negative health effects (Young *et al.*, 2017) preventive measures are recommended for individuals of all skin types (Agbai *et al.*, 2014; Tod *et al.*, 2024). Preventive measures include avoidance of exposure through scheduling work outside of peak exposure hours, shade seeking during breaks where available, the wearing of photoprotective clothing, wide brimmed hats, and sunglasses, and application of sunscreen (Milon *et al.*, 2014; Peters *et al.*, 2020; Ruales *et al.*, 2022; Tod *et al.*, 2024). Avoiding exposure during the midday peak solar UVR period is not a feasible preventive measure for outdoor workers (Merin *et al.*, 2022). In a study population that included teachers, the use of sunscreen was ranked highest, followed by variations in avoiding midday exposure and the use of sunglasses, while the wearing of long-sleeved shirts and trousers were the least favoured means of protection (Blázquez-Sánchez *et al.*, 2021). The existence of population group and gender differences in the usage of sunscreen has been demonstrated (Dlova *et al.*, 2018; Holman *et al.*, 2019; Diffey *et al.*, 2020; Fliorent *et al.*, 2023). More specifically, the frequency of sunscreen usage was reported to be lower in men due to their belief and adherence to masculinity roles (Mackenzie *et al.*, 2019), individuals with darker skin phototypes (Dlova *et al.*, 2018; Fliorent *et al.*, 2023), and older population groups (Mackenzie *et al.*, 2019).

Increasing awareness and understanding of unsafe conditions for going outdoors without protection, particularly through comprehending the UVI, can contribute to lowering overall exposure to solar UVR (Lim and Cooper, 1999). Therefore, training

on solar UVR as a workplace hazard plays an important role in informing outdoor workers about the associated health risks (Ruales *et al.*, 2022). Sun safety training tends to change workers' perception about workplace safety culture and consequently change their behaviour particularly when conducted in groups (Cavazza and Serpe, 2010; Durand *et al.*, 2022). Also, knowledge correlated with the likelihood of engaging in positive skin protective behaviours (Dlova *et al.*, 2018). However, findings point to the role played by perceived risk which serves as a barrier to workers' practice of photoprotective measures in different population groups (Buster *et al.*, 2012; Fliorent *et al.*, 2023). More specifically, individuals with darker skin types believe that their skin is not affected by exposure to solar UVR (Coups *et al.*, 2012; Lunsford *et al.*, 2018).

Workers demonstrated varying levels of knowledge and understanding of solar UVR exposure as a health hazard in previous studies (Bryant *et al.*, 2015; Houdmont *et al.*, 2016). In Africa, findings from the few studies that have been carried out show that workers in occupations such as car guarding and forestry (Nkogatse *et al.*, 2019; Rother *et al.*, 2020), lack education related to solar UVR. However, such studies have not been conducted in the mining sector. Therefore, to fill this gap, the objective of the study was to evaluate knowledge, attitudes, and behaviours and their relations related to solar UVR exposure of opencast outdoor mine workers in Namibia.

Methods

Research ethics

The study was conducted with the ethics approval from the North-West University Health Research Ethics Committee (NWU-00031-17-A1) and the Namibia Ministry of Health and Social Services (17/3/3/CR). An independent person explained the aims of the study to all workers, obtained participants' written consent, gave questionnaires to consenting workers, and received completed questionnaires.

Study design, population, and location

This cross-sectional study was conducted at two opencast mining operations in the Karas region, Namibia, referred to as site A (Latitude: 28° 10 16 S; Longitude: 16° 52 1 E) and B (Latitude: 28° 15 47 S; Longitude: 16° 48 12 E) depicted in Figure 1. Workers in these mining operations were categorised according to the activities they carried out, namely, Bedrock workers, engineers, metallurgy workers, and security

attitudes, and three questions for behaviours (Table 1). The questionnaire also included probing questions such as where on the body was sunscreen applied, frequency of sunscreen reapplication, the sun protection factor (SPF) of the sunscreen used, and the type of hat and clothing protection worn.

Table 1. Knowledge, attitude, and behaviour questions together with the scoring system as described below.

Variable	Question	Score for each item	Section total
Knowledge	It is good to spend a little time in the sun every day.	No 1, Yes 0	4
	Do you know what UVI is?	Yes 1, No 0	
	Do you know what SPF is?	Yes 1, No 0	
	Did you receive sun safety education and training in your previous job and / or current job?	No 0, Once or two times or more than two times 1	
Attitude	I stay for long periods of time in the sun to look more tanned or to darken my skin.	Yes 0, No 1	2
	Somebody that is tanned or has a darker skin is more attractive.	Yes 0, No 1	
Behaviour	Do you apply sunscreen while working in the sun?	Never 0, Sometimes or always 1	3
	How often do you wear a hat when outdoors during working hours?	Never 0, Sometimes or always 1	
	How often do you wear eye-protection (sunglasses) when outdoors during working hours?	Never 0, Sometimes or always 1	
Total score			9

Data management and statistical analysis

Due to the small sample sizes, the data from the two mining operations were pooled and recorded using the REDCap software (Version 6.1.3) (Harris *et al.*, 2009). The questions in Table 1 were used to calculate descriptive statistics and frequencies. The frequencies were calculated using the total number of responses received per question with unknowns not taken into consideration. This was followed by data coding according to knowledge, attitude, and behaviour scores with further analysis using STATA (version 18). The association between knowledge, attitude, and behaviour scores was evaluated using Pearson's pairwise correlations. Fisher's exact test was used to determine the association between individual and combined knowledge, attitude, and behaviour scores, and worker sociodemographic characteristics, including work site, gender, ethnicity, and level of education. A $p \leq 0.05$ was considered statistically significant.

Results

The study was carried out during winter when the temperature in the Karas region, Namibia ranged from a minimum of 8°C to a maximum of 23°C, and the average noon ultraviolet index (UVI) was four (Ramotsehoa *et al.*, 2024). The noon solar zenith angle (SZA) was 52° over the four measurement days for site A and ranged between 56° and 95° for site B (Solcast, 2024).

Sociodemographic profile of workers

The median age of the participating workers ($n = 36$) was 39 years (range 30 – 49 years), with men comprising 88% of the sample (Table 2). Eighty percent of the participating workers classified themselves as black Africans. The levels of education of workers ranged from a lack of education (11%) to having completed different levels of secondary education (78%), and fewer (11%) who completed tertiary education. Sixty-five percent of the workers were employed in their current job for between one and five years.

Table 2. Sociodemographic data of the outdoor workers

Variable	Frequency (n)	Frequency (%)
^a Gender:		
Male	30	88
Female	4	12
^b Population group:		
Black African	28	80
Coloured	5	14
White	2	6
^c Highest completed education level:		
No schooling	3	11
Grade 9	1	3
Grade 10	7	25
Grade 12	14	50
Tertiary education	3	11
^d Number of years in the current job:		
1-5	20	65
6-10	3	10
11-15	6	19
>16	2	6

Number of responses received per variable: a = 34, b = 35, c = 28, d = 31

Knowledge, attitudes, and behaviour scores related to photoprotective measures

The responses to the questions scored related to knowledge, attitude, and behaviour, indicated in Table 1 are presented in Table 3. Sixty-five percent of the participants were in support of the statement that it is good to spend some time in the sun, and 60% did not know what UVI was. Ninety-two percent of respondents received no sun safety education and training. Few workers (8%) indicated that they intentionally spend more time outside to darken their skin, while 48% found someone with darker skin more attractive. A total of 9% of the participating workers stated that they always applied sunscreen when working outside with the face as the main application area. However, 60% of the respondents did not know the SPF of the sunscreen they used and 11% of the users reapplied every 5 hours. Regarding the cost implication of sunscreens, 58% of the workers indicated that they could not afford sunscreens. Eighty-one percent of the workers selected the standard hard hat issued in the workplace as the main protection for the head and face areas, while only 6% of the workers selected the use of a wide-brimmed hat. Sunglasses were always worn by 30% of the workers, while 64% of the workers indicated that they sometimes wore them when working outdoors. Regarding the type of clothing worn, 97% of the workers

chose workplace-issued coveralls with long sleeves and long trousers. The other protective clothing options, such as long-sleeved T-shirts and shirts, received lower preference.

Relations between knowledge, attitudes, and behaviours

Pearson pairwise correlations were used to determine the relationships between knowledge (0.77 ± 0.88 range 0-3), attitude (1.29 ± 0.71 range 0-2) and behaviour (2.29 ± 0.52 range 1-3) scores, and no significant correlation was found. Similarly, Fisher's Exact test showed that the relationship between individual knowledge, attitude, and behaviour scores, and worker sociodemographic characteristics were not statistically significant. This could have been due to the small sample sizes within the scores which were grouped into categories. The results of the Fisher's Exact test to determine the relationship between individual participant socio-demographic characteristics and the combined total scores for knowledge, attitude, and behaviour showed a statistically significant relationship with the level of education ($p = 0.014$).

Table 3. The scored knowledge, attitude, and behaviours variables of the workers (N=36).

	Variable	Frequency (n)	Frequency (%)
Knowledge	^e It is good to spend a little time in the sun every day: No Yes I do not know	7 22 5	20 65 15
	^f Do you know what UVI is? Yes No	13 20	40 60
	^g Do you know what SPF is? Yes No	4 5	44 56
	^h Did you receive sun safety education and training in your previous job and / or current job? No Once Two or more times	21 1 1	92 4 4
Attitudes	ⁱ I stay for long periods of time in the sun to look more tanned or to darken my skin: Yes No	2 22	8 92
	^j Somebody that is tanned or has a darker skin is more attractive: Yes No	13 14	48 52
Behaviours	^k Do you apply sunscreen while working in the sun? Never Sometimes Always	22 9 3	65 26 9
	^l How often do you wear a hat when outdoors during working hours? Never Sometimes Always	0 7 29	0 19 81
	^m How often do you wear sunglasses when outdoors during working hours? Never Sometimes Always	2 23 11	6 64 30

Number of responses received per variable: e=34, f=33, g=9, h=23, i=24, j=27, k=34, l=36, m=36.

Discussion

The findings of this study show that most of the participants (80%) classified themselves as black African descent, were middle aged, and had completed varying levels of education. There was a general lack of education and training on sun safety and low use of sunscreen with insufficient reapplication by those who reported that they always applied sunscreen. Hard hats, safety goggles, long sleeves and long trousers were understandably selected by most workers, as they are standard issue in the two mining operations. Overall, the level of education of the worker was statistically significantly associated with their combined knowledge, attitude, and behaviour scores. Therefore, the higher the level of education, the higher the knowledge related to the sun and the positive attitudes and behaviours.

Although no relationship was established between skin type and knowledge of photoprotective measures in this study, Calderóna *et al.* (2019) found that individuals with darker skin types had relatively low knowledge of sun-related risks and photoprotective measures, leading to lower compliance with prevention strategies. Furthermore, the low use of sunscreen found in this study is consistent with the findings of a previous study that involved farmers, roofers and gardeners (Zink *et al.*, 2017), and more specifically among individuals of darker skin types (Buller *et al.*, 2011; Wright *et al.*, 2014). Coups *et al.* (2012) also established that the use of photoprotective clothing was higher in individuals with lighter skin types than in those with darker skin types.

Regarding gender, 88% of workers being males is of relevance, since the likelihood of using photoprotective measures was found to be lower in males (Hourani and LaFleur, 1995; Lewis *et al.*, 2006; Nahar *et al.*, 2014; Mulenga *et al.*, 2019). Furthermore, the social norms related to masculinity have led to a much lower use of sunscreen in men (Holman *et al.*, 2015; Tsai and Chien, 2023). Although the benefits of sunscreen use among people with dark skin centre around prevention of dermatological illnesses, and less so for skin cancer (Song *et al.*, 2021), efforts to support sunscreen use among at-risk groups such as the 20% of workers with lighter skin types in this study are important.

The statistically significant relationship between the level of education and knowledge of solar UVR and the practice of photoprotective behaviour was also found in other studies (Thomas-Gavelan *et al.*, 2011; Coups *et al.*, 2012; Agarwal *et al.*, 2018). More specifically, findings from other studies established an association between education and the wearing of protective shirts and trousers (Andreeva *et al.*, 2010), wearing of sunglasses (Chen *et al.*, 2021), and the use of sunscreen (Falk and Anderson, 2013). Additionally, the likelihood of improving sunscreen use among those with lower education levels was low (Falk and Anderson, 2013).

Globally, occupational health and safety legislation obligates the employer to inform, educate and train workers about the hazards to which they are likely to be exposed, the health effects related to exposure, and the protective measures available to them (ILO, 2018). Nonetheless, this study discovered that 90% of the workers indicated a general deficiency in education and training regarding sun safety and the risks associated with solar UVR exposure. This factor could have contributed to the workers using fewer photoprotective measures than found in this and other studies (Pengpid *et al.*, 2015; Agarwal *et al.*, 2018; Nkogotse *et al.*, 2019). However, a study by Houdmont *et al.* (2016) found that training and good knowledge of sun safety measures were not a predictor of practising positive photoprotective behaviours.

A central principle of many health decision-making models is that preventive health behaviours are partly motivated by the perception that a person may experience a specific health problem (Noar and Zimmerman, 2005). Therefore, the belief that individuals with darker skin types do not require protection from sun UVR exposure (Kim *et al.*, 2009; Wright *et al.*, 2014; Cestari and Buster, 2017; Rodriguez *et al.*, 2017) due to a combination of a lower incidence of skin cancer (Tod *et al.*, 2019), and an underestimation of their risk (Zink *et al.*, 2018), may explain the relatively low use of photoprotection observed in this study.

The hard hats or helmets worn by most of the workers in this study as means of protection of the head and face are required within the mine premises. Therefore, the general recommendation for the wearing of wide-brimmed hats would be desirable for occupations such as farming and not mining (Modenese *et al.*, 2020). Hardhats were shown to be effective in protecting the neck during summer and not in winter (Backes

et al., 2019). Although no single hat provides 100% protection (Backes *et al.*, 2019), workers in this study could benefit from additional neck covering and sunscreen application. In addition to the excessive cost of sunscreen shown to be a barrier in this study, greasiness and the white residue left by many products make sunscreen undesirable, especially among people with darker skin types, (Song *et al.*, 2020). The need for reapplication, which is either omitted or exercised improperly by 35% of the workers who indicated that they always applied sunscreen in this study, affects the use of adequate amounts of sunscreen (Mahler, 2014). Thus, Tizek *et al.* (2017) recommended the provision of a sunscreen dispenser and education and training on the proper use of sunscreen at the workplace to improve use and reapplication.

Eye diseases such as eyelid malignancies [basal cell carcinoma (BCC) and squamous cell carcinoma (SCC)], photokeratitis, climatic droplet keratopathy (CDK), pterygium, and cortical cataract are caused by solar UVR exposure related to outdoor work (Backes *et al.*, 2019). Risk can be reduced by wearing sunglasses (Backes *et al.*, 2019), a practice that was found to be poor in this study. Since safety goggles are issued to workers for protection of their eyes against splashes, it would be ideal to select those that offer UVR protection (Tubert, 2023).

Photoprotective clothing is another important line of defence against solar UVR exposure (Gies, 2007). Workers indicated that they knowingly or otherwise were adequately protected by always wearing long sleeves and long trousers, and this was similar to findings by Andreeva *et al.* (2010). Reliance on work gear as the most common protective measure was also found in park workers (Nahar *et al.*, 2014).

Study limitations

Self-completed questionnaires with unchecked responses to certain questions resulted in an incomplete data set. It is not clear whether the lack of response was indicative of a lack of knowledge. Additionally, self-completed reporting has limitations when it comes to determining the effective use of sunscreen (Julian *et al.*, 2023). Conducting the study during winter may have produced recall bias, which therefore highlights the need to repeat the study during summer.

Conclusions

The general lack of education and training on the hazards of exposure to solar UVR was identified in this study. Poor sunscreen use would pose a risk to workers of all skin types. The clothing issued to the workers offered adequate protection, and these were selected by the workers. The likelihood of having positive attitudes and practising good photoprotective behaviours would be higher in workers with higher levels of education. With the mining workers being at different levels of education and ethnicities, sun safety messages that are tailor-made for the different groupings are required. The provision of sunscreen, solar UVR protective eye protection, and the addition of an extension flap to the hard-hat could improve worker protection since workers rely on standard workplace personal protection equipment (PPE).

What is important about this manuscript

The manuscript highlights the deficiency in sun safety training and inadequate use of photoprotective measures in the selected opencast diamond mining operations. The findings indicate that education level is a predictor of strong awareness about the risks of solar UVR exposure and favourable attitudes and behaviours regarding the use of photoprotective measures. Therefore, emphasis needs to be placed on providing sun safety training to workers with lower educational levels, who represented the majority of the study's population.

Conflict of interest

The authors have no conflict of interest to declare.

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CHAPTER 6: CONCLUSIONS, LIMITATIONS, RECOMMENDATIONS AND FUTURE STUDIES

This chapter provides a summary of conclusions and limitations of this thesis. Recommendations are made with the aim of providing the workers and management of the two opencast diamond mining operations with measures they can use to reduce personal exposure to solar UVR. Future studies are also proposed.

The aim of this thesis was to quantify personal solar UVR exposure of outdoor workers at two opencast mining operations in Namibia with consideration of skin colour and effectiveness of protective clothing. The knowledge, attitudes and behaviour related to the risk of exposure to solar UVR of these workers were also evaluated.

6.1 Conclusions

6.1.1 Exposure to solar UVR

Exposure to solar UVR of outdoor workers in general and those in open-cast mining operations presents a major risk to their occupational health and safety (Milon *et al.*, 2014; ILO, 2018; Slavinsky *et al.*, 2024). This is because of the ubiquitous nature of exposure and avoidance that is not always an option (ICNIRP, 2010). Personal exposure and exposure as a percentage of ambient solar UVR were found to be higher in winter than summer respectively which corresponds to other studies conducted in Australia (Neale *et al.*, 2010; Downs *et al.*, 2014). The lack of solar UVR exposure data in opencast diamond mining contributes to the lack of knowledge about exposure patterns particularly because winter is excluded in most studies (Lucas *et al.*, 2016; Nkogatse *et al.*, 2019; Peters *et al.*, 2020; Cherrie *et al.*, 2021; Linde *et al.*, 2022).

The first objective of this thesis was to measure personal exposure of Namibian outdoor opencast mineworkers to solar UVR at different body positions using electronic dosimeters and PSF badge dosimeters during winter. The objective was achieved using electronic dosimeters based on Schottky Aluminium Gallium Nitride (AlGaN) photodiode worn on the wrist and PSF dosimeters (PSF badges) attached to the hard hat, nape, shoulder, and wrist. Chapter 3 of this thesis reports on electronic dosimeter measurements in a manuscript titled 'Solar ultraviolet radiation exposure among opencast miners in Namibia with the use of electronic dosimeters: a feasibility

study'. The manuscript is published in the journal, *Annals of Global Health*. The solar UVR exposure data obtained using PSF badges are covered in Chapter 4 in a manuscript titled solar ultraviolet radiation exposure of mineworkers in selected opencast mining operations in Namibia.

The mean daily ambient solar UVR measured with electronic dosimeters peaked between 12:00 and 13:00 for site A (Chapter 3, Figure 2a) while that of site B (Chapter 3, Figure 2b) was between 14:00 and 15:00. The differences in peak ambient solar UVR were as a result of different times (dates) of measurements at the two mining operations. The findings of electronic dosimeters attached to the wrists of nine workers with valid data (Chapter 3) showed that the mean daily solar UVR exposure of 89% of the workers from the two mining sites combined, exceeded the upper limit of the ICNIRP exposure guideline of 1.3 SED over an 8-hour period. More specifically the mean daily solar UVR exposures were 1.9 ± 1.0 (1.01 to 3.39) SED. Therefore, the mean daily solar UVR exposure exceeded the ICNIRP guideline. The corresponding mean daily exposure as percentage of ambient solar UVR was $18.8 \pm 9.5\%$ (9.5 to 32.1%) for site A. For site B, the mean daily solar UVR exposure and exposure as percentage of ambient solar UVR were 3.4 ± 2.6 SED (1.5 to 7.2) SED (which was 2.6 times above the ICNIRP exposure guideline), and $34.1 \pm 25.6\%$ (15.34 to 71.1%) respectively.

For PSF badges (Chapter 4), the mean daily solar UVR exposure dose received on all body positions (2.07 – 3.69 SED) (Figure 1) and job categories (2.00 – 3.11 SED) (Figure 2) exceeded the upper limit of the ICNIRP solar UVR exposure guideline of 1.3 SED with the head receiving the highest mean daily exposure. Also, statistically significant differences were found in both the mean daily solar UVR exposures (Chapter 4, Figures 1 and 2) and mean daily exposure as percentage of ambient solar UVR (Chapter 4, Table 2) for the combined body positions and job categories. The mean daily exposure as percentage of ambient solar UVR (Chapter 4, Table 2) for the head (with the maximum of 214.69%) was statistically significantly different to that received on the neck and wrist. Regarding exposures as percentages of ambient solar UVR by job categories, statistically significant differences were found between Bedrock workers and both Engineering ($34.46 \pm 36.36\%$) and Metallurgy workers (29.15 ± 23.88) while Engineering workers (214.69%) received the highest maximum.

For comparison between electronic dosimeter and PSF badge personal solar UVR measurements, the overall mean daily solar UVR for site A and B (Chapter 3, Table 2) obtained using electronic dosimeters was calculated. Electronic dosimeters produced a mean daily solar UVR of 2.60 ± 1.92 SED on the wrist and the corresponding exposure for PSF badges was 2.43 ± 2.23 SED received on the wrist. These mean daily exposure doses were not statistically significantly different ($p = 0.3275$). The finding contrasts with the reported differences of 20% to 30% between these two dosimeters, where exposure was exaggerated by the PSF dosimeters (Strehl *et al.*, 2021). Also, a smaller standard deviation produced by electronic dosimeter data (Strehl *et al.*, 2021) was not observed in this thesis. Therefore, both dosimeters are suitable for measuring exposure of open-cast mineworkers to solar UVR. However, the smaller number of valid data points produced by electronic dosimeters because of dosimeter failure, could have skewed the results and are a concern. PSF dosimeters are more suitable for measuring exposure at different body positions due to their small size and weight (Diffey, 2020).

Excessive solar UVR exposures were also measured on the heads of Australian cyclists (Kimlin *et al.*, 2006), and wrists and chests of construction, physical education teachers, and farmers in New Zealand in winter (Gies *et al.*, 2014). In contrast, solar UVR exposures that were lower than the INCIRP exposure guideline were reported for Australian outdoor workers (0.91 SED) on the chest, shoulder and body (Downs *et al.*, 2019), and Australian teachers (0.91 SED) on the nape (Neale *et al.*, 2010) during winter. In this thesis, the mean daily solar UVR measured on the head (3.69 ± 3.48 SED), neck (2.07 ± 2.27 SED), and shoulder (2.71 ± 2.28) were higher than those measured in previous studies (Kimlin *et al.*, 2006; Neale *et al.*, 2010; Downs *et al.*, 2019). The postures assumed in the different job categories in this thesis and other studies could account for the differences observed in exposure patterns at different body positions (Schmalweiser *et al.*, 2010; Vernez *et al.*, 2015). Furthermore, the higher exposures received on the head and shoulder in this thesis were consistent with the higher exposure received on the upper body positions in other studies (Reeder *et al.*, 2013; Vernez *et al.*, 2015).

The finding of this thesis points to the importance of including all seasons, job categories, and body positions other than the wrist in solar UVR exposure

measurements. Therefore, the hypothesis (hypothesis 1 in Chapter 1) that the solar UVR exposure of Namibian outdoor opencast mineworkers on different body positions during winter exceeds the ICNIRP exposure guideline of 1.0 to 1.3 SED over an 8-hour period, is accepted.

6.1.2 Skin colour

The second objective of this thesis was to establish the constitutive and facultative skin colour of Namibian outdoor opencast mineworkers. Using a calibrated colorimeter, individual typology angle (ITA) was measured on the volar upper arm for constitutive (photoprotected) skin colour and dorsal forearm for facultative (photoexposed) skin colour. Findings presented in Chapter 4, Table 1, showed that the constitutive skin colour of workers were classified into phototype III to VI. A higher percentage (49%) of the facultative skin phototypes of workers were in phototype VI. This indicated a darkening of the skin due to solar UVR exposure (photoexposure). Statistically significant differences were found within phototype V, VI, total (combined) ITA and between combined ITA of photoprotected and photoexposed skin ($p \leq 0.05$). The diversity and differences within the same ethnic groups in darker skin phototypes are responsible for the observed differences (Green, 2023; Krutmann *et al.*, 2023).

Namibia's population is comprised of 87% darker skin phototypes (Namibia Statistics Agency, 2024), and this was reflected in the higher percentage of constitutive and facultative skin phototypes classified as phototypes V and VI in this thesis. Eighty percent of these outdoor opencast mineworkers classified themselves as Black Africans as reported in Table 2 of Chapter 5. The skin of outdoor workers adapts to chronic exposure to solar UVR through pigment darkening (ICNIRP, 2010; Yardman-Frank and Fisher, 2021). This accounted for the significant differences found in ITA between photoprotected and photoexposed skin phototypes. The finding highlights the physiological and dermatological importance of objective skin colour measurements (Del Bino and Bernerd, 2013). According to Naik and Farrukh (2022) the combination of melanin, carotenoids, haemoglobin, and oxyhaemoglobin is responsible for the different tones in darker skin phototypes and explains the significant differences observed within brown (phototype V) and dark (phototype VI) skin phototypes in this thesis. Although workers with darker skin types are at a reduced risk of developing skin cancer than those with lighter skin phototypes (Munjal and Ferguson, 2023), they

are equally susceptible to eye diseases, immunosuppression, photoaging, and hyperpigmentation disorders caused by exposure to excessive solar UVR (Fajuyigbe and Young, 2016; Lucas *et al.*, 2016; Schmalwieser *et al.*, 2021; Markiewicz *et al.*, 2022).

In conclusion, findings of this thesis show that objective measurement of skin phototype (colour) using skin bioengineering instruments is more accurate than subjective, self-reported skin phototyping where questions related to sunburn are used, a foreign concept for those with darker skin phototypes. The use of objective skin phototype determinations should be extended to workers with darker skin phototypes seeing that variations are found even in the same ethnic group (Krutmann *et al.*, 2023).

Differences in skin colour (pigmentation) between constitutive (photoprotected) and facultative (photoexposed) skin were determined, and thus the second objective of the study was achieved. The hypothesis (hypothesis 2, Chapter 1) that the ITA measured on photoprotected skin differs significantly from that measured on photoexposed skin of opencast mineworkers is accepted because it was shown in Chapter 4 that the ITAs of photoprotected and photoexposed skin phototypes are statistically significantly different.

6.1.3 Effectiveness of photoprotective clothing

Evaluation of the effectiveness of clothing as a protective measure against solar UVR exposure was the third objective of this thesis. This objective was achieved using PSF badge dosimeters placed under and above clothing on the shoulder during winter. The personal protective equipment issued and worn by outdoor workers at two opencast mining operations were coveralls with long-sleeves and long trousers, hard hats, and goggles. Findings reported in Chapter 4 (Figure 3) showed that the combined mean daily solar UVR exposure received above clothing (2.73 ± 2.26 SED) was statistically significantly higher than that received under clothing (0.08 ± 0.27 SED). In practical terms, the clothing effectively blocked 97.1% of the solar UVR from reaching the skin on the shoulder.

Sun safety measures should be inherently guided by the workplace to ensure that they are relevant to their own context and take advantage of existing social networks (Sendall *et al.*, 2016). Clothing is an important part of photoprotection against negative health effects of solar UVR such as erythema (Aguilera *et al.*, 2014; Boothby-Shoemaker *et al.*, 2022). Excessive mean daily solar UVR exposures (Chapter 4, Figure 1 and 2, and Table 2) received on the upper body positions emphasises the need for additional photoprotective measures such as a flap attached to the back of the hard hat, sunglasses or UV resistant goggles, and sunscreen for exposed skin (Ruales *et al.*, 2022). With the lower perceived risk of sunburn and skin cancer in individuals with darker skin phototypes, compliance to photoprotective measures should be evaluated (Liu *et al.*, 2016; Maymone *et al.*, 2017).

The hypothesis (hypothesis 3, Chapter 1) that the type of clothing issued and worn by outdoor mineworkers effectively blocks solar UVR, is accepted because the findings reported in Chapter 4 show that solar UVR measured under clothing was significantly lower than that measured above clothing on the shoulder.

6.1.4 Knowledge, attitude, and behaviours

The fourth objective of the study was to evaluate the Namibian outdoor opencast mineworkers' knowledge, attitudes, and behaviours related to the risk associated with chronic solar UVR exposure and photoprotection measures. This objective was achieved by making use of a questionnaire. The questionnaire was used in a previous South African study (Nkogatse *et al.*, 2019).

The lack of knowledge and poor use of photoprotective measures is shown in Chapter 5. A high percentage (65%) of workers regarded spending time in the sun as a good thing and 60% of the workers did not know what UVI is. The use and reapplication of sunscreen, and the knowledge of the SPF of the sunscreen was poor, while sunglasses were always worn by 30% of the workers. Standard workplace-issued hard hats and coveralls with long sleeves and long trousers were the protective measures of choice. The level of education had a statistically significant association with the combined scores of knowledge, attitude, and behaviours.

The lack of knowledge about photoprotective measures against solar UVR exposure was also found in South African car guards (Nkogatse *et al.*, 2019) and farmers in Turkey (Asil *et al.*, 2024). Other studies found that workers with greater knowledge of the health risks of exposure to solar UVR either did not effectively use the different photoprotective measures (Fernandez-Ruiz *et al.*, 2022) or lacked knowledge about photoprotective measures (Cambil-Martin *et al.*, 2023). In agreement with findings in this thesis, workers with higher levels of education knew about the different means of photoprotective measures (Agarwal *et al.*, 2018). Thus, John *et al.* (2016) recommended the implementation of education programs aimed at improving health literacy and changing worker behaviours.

The hypothesis (hypothesis 4, Chapter 1) that Namibian outdoor opencast mine workers lack knowledge about the hazards and the appropriate protection measures related to solar UVR exposure is accepted.

6.1.5 Summary

The outdoor opencast mineworkers at the two mining operations in Namibia are at the risk of developing negative health effects on the head, shoulder, neck, and wrist with the head at the highest risk irrespective of the job categories. The higher amount of melanin in darker skin phototypes identified in this thesis, is not a guaranteed photoprotective measure against hyperpigmentation, photoaging, and eye conditions caused by excessive solar UVR exposure. Workplace-issued coveralls were effective in protecting workers' skin on the shoulder. Additional photoprotective measures such as flaps attached to the back of the hard hat, UV protective goggles, application of sunscreen are required for protection of the neck, eyes, and bare skin. The workers' knowledge of the risks of excessive solar UVR exposure and attitudes and behaviours related to the use of photoprotective measures were shown to be related to the level of education. This finding is significant, seeing that most workers did not advance beyond high school education.

The aim of this thesis namely, to quantify personal solar UVR exposure of outdoor workers at two opencast diamond mining operations in Namibia with consideration of skin colour and effectiveness of protective clothing, and to evaluate the knowledge, attitudes and behaviour related to the risk of exposure to solar UVR, was achieved.

6.2 Recommendations

Recommendation 1: Exposure measurements dosimetry.

In this thesis, Chapter 3 reports on electronic dosimeter exposure data while PSF badge data is reported in Chapter 4 (Figure 1 and 2, and Table 2). The exclusion of 67.85% of the workers' solar UVR exposure data because of the errors experienced with electronic dosimeters in this thesis and another study (Køster *et al.*, 2015) overshadow the ability of measurement of diurnal variations (time-stamped data) that is possible with electronic dosimeters. Therefore, consultation with the manufacturer, Prof Martin Allen (University of Canterbury, Canterbury, New Zealand) regarding the possibility of upgrading the electronic dosimeters to a more stable and reliable dosimeter is required. Until that is achieved, the electronic dosimeters are not recommended for measurement of occupational exposure of outdoor diamond opencast mineworkers to solar UVR. The use of alternative electronic dosimeters such as GENESIS UV system (DGUV, 2022) that is widely used in Europe (Moldovan *et al.*, 2020; Wittlich *et al.*, 2020), allows for longer term measurements in different occupations and should be explored. Consideration of availability, shipment arrangement and costs for the GENESIS UV system is required. These dosimeters can only be worn using a strap on the upper arm which limits exposure to different body positions.

The PSF badge dosimeters has been in use since its discovery in the mid 1970's (Diffey, 2020). Their use comes with acknowledgement of shortcomings that include inability to provide for diurnal variations, saturation of the badges when solar UVR doses are high, 1.4% variations in solar UVR measured by the badges from the same batch, and cost of single use (Vernez *et al.*, 2015; Diffey, 2020). The small size and ease of attachment allow for total daily solar UVR exposure measurements for different body positions. Therefore, the PSF is recommended for the measurement of solar UVR exposure of outdoor opencast mineworkers in Namibia.

Recommendation 2: Low-cost colorimetric dosimeters.

Employers should consider investing in low-cost electronic dosimeters that can be used as indicators of solar UVR exposure in between exposure measurements with validated dosimeters. The first example of a low-cost dosimeter is based on 3,3', 5,5'-tetramethylbenzidine (TMB). The TMB oxidizes rapidly when exposed to UVB in a

dose dependent manner. Worn as a bracelet with TMB infused paper, it gives a colour indication when UVB exceeds the MED (Zhang *et al.*, 2022). The second example is the 2,3,5-triphenyltetrazolium chloride embedded in a poly (vinyl alcohol) matrix which is also worn as a bracelet that changes colour in dose dependent manner (Jaszczak-Kuligowska *et al.*, 2024). Usage of such dosimeters will empower outdoor workers into making decisions about their own solar UVR exposure and encourage the use of photoprotective measures.

Recommendation 3: Reduction of exposure.

Outdoor workers receive higher exposure to solar UVR than the general population (Wittlich *et al.*, 2020). Solar UVR data from the two dosimeters presented in Chapters 3 and 4, indicated that workers are at the risk of high exposure to solar UVR during winter. Considering that most of the workers' skin phototypes were classified as phototype V and VI in this thesis, their motivation for photoprotection is much lower (Tsai and Chien, 2022) because of the perceived lower risk of most negative health effects of solar UVR. Therefore, the inclusion of all photoprotective measures according to the hierarchy control (Ruales *et al.*, 2022) deserves consideration. Since avoidance of peak exposure is not feasible in mining operations in this thesis, the feasibility of providing a shade structure (engineering control measure) for use during breaks and rotation of work activities during peak periods (administrative control measure) should be investigated (Peters *et al.*, 2020; John *et al.*, 2021; Cherrie and Cherrie, 2022). Interestingly, people with darker skin types have reported the use of shade when available and long-sleeved clothing as their preferred means of protection (Tsai and Chen, 2022). Thus, the Namibian opencast mining operations should capitalise on this aspect in the provision of photoprotective measures.

Recommendation 4: Solar UVR exposure legislation.

According to John *et al.* (2021), the lack of legislation for occupational solar UVR exposure is a global problem, and Namibia is no exception (Republic of Namibia, 2007). For many years, the ICNIRP recommended a range of 1.0 to 1.3 standard erythemal dose (SED) based on the International Commission on Illumination (CIE) action spectrum as an exposure guideline over an 8-hour period (CEN, 2008; ICNIRP, 2010). The exposure guideline is aimed at the prevention of acute health effects of the skin and eyes (ISO, 2019). Therefore, the exposure guideline should be used with

caution in Africa because it does not protect against chronic exposure of the eyes and immune system to excess solar UVR (Agbai *et al.*, 2014; Fajuyigbe and Young, 2016). Among the aspects raised in the 'Global Call to Action to Protect Outdoor Workers from Skin Cancer by Solar Ultraviolet Radiation Exposure' that are relevant to the mining operations in Namibia, is the efficient protection of outdoor workers through the formulation and enforcement of legislative framework for occupational solar UVR exposure by the World Health Organization (WHO) (Röcken *et al.*, 2023). The development of solar UVR exposure legislation that will consider climates in Namibia and other African countries, impact of climate change on solar UVR patterns and occupational exposure to solar UVR should be explored. The Southern African Institute of Occupational Hygiene (SAIOH) to which all occupational hygiene practitioners in Southern Africa are affiliated, the ILO, and Namibian Ministry of Labour, Department of Employment and Labour (South Africa) are better placed to take the lead on the development of solar UVR exposure legislation for Southern African countries.

Recommendation 5: Photoprotection.

The employer's obligation to protect workers who may be exposed to solar ultraviolet radiation is the only aspect mentioned in the Namibian Occupational Health and Safety Act (Republic of Namibia, 2007). In addition to the long-sleeved coveralls, a neck flap for the hard hats, goggles with UV protective lenses and sunscreen, funded by the mining company, should be introduced into the general workplace safety program. Findings of this thesis presented in Chapter 5 indicated an overall lack of knowledge of photoprotective measures by the Namibian outdoor opencast mineworkers. The small percentage (8%) of workers who reported the use of sunscreen, proper use and reapplication was poor.

An 18-month intervention program was developed in 14 Australian companies of varied sizes with workplace champions recruited within those companies. Tailor-made strategies that are supported by sun protection by policy were developed to include the provision of shade structures, the supply of personal protective equipment, education and training that included posters around the workplace, supervisors and senior personnel acting as role models, and annual skin examinations (Rye *et al.*, 2014). Assessment after the intervention showed positive changes in knowledge,

attitudes, and behaviours, and this strategy should be adopted by mining operations in Namibia.

Thus, ongoing training and instruction on the different photoprotective measures is recommended. Also, an assessment of compliance with provided photoprotective measures, especially personal measures such as the application of sunscreen, wearing of wide brimmed hats and sunglasses, and shade seeking behaviours, should be done on a regular basis due to lower use identified in this thesis and other studies (Peters *et al.*, 2016) and the inherent underestimation of the risk of exposure to solar UVR in individuals with darker skin phototypes (Peters *et al.*, 2020; Tsai and Chen, 2022).

6.3 Limitations of the study

This section outlines the limitations of the study.

Limitation 1

Since only two mining sites were included in the study, the results cannot be extrapolated to the entire country or other mining operations. Furthermore, due to the sensitive nature of diamond mining operations, factors that may influence exposure, such as detailed information on daily tasks and conditions in the work environment, were not available. For these same reasons, it was not possible to observe the use of available shade structures by workers during lunch breaks. Due to logistical challenges, solar UVR exposure measurements were carried out over four days, and this presented a limitation of the study.

Limitation 2

The ability to produce time-stamped personal solar UVR exposure is a strength of electronic dosimeters. The disadvantage of electronic dosimeters is that the closed design lacked a fault indicator during measurements, and a researcher does not become aware of this until data are downloaded onto a personal computer. The failure of electronic dosimeters to transfer data in this thesis and during calibration presented a limitation to the measurements similar to those reported by Køster *et al.* (2015) for the same type of electronic dosimeters.

Limitation 3

The PSF badges are simple to use and do not interfere with job activities even though, the determination of exposure variations throughout the work shift is not possible. This is an important aspect of exposure measurements since the diurnal variations are different at different body positions (Hu *et al.*, 2010). The need to measure post-exposure absorbance could present a limitation when the mining company must send badges to a laboratory for that purpose. To mitigate this limitation, the mining company could obtain their own spectrophotometer and have an employee trained to perform the analysis on site. Nevertheless, the findings contribute to the knowledge base of solar UVR exposure of outdoor opencast mineworkers.

Limitation 4

Self-completed questionnaires with unchecked responses to certain questions were received in this thesis and this resulted in an incomplete data set. The reasons for the lack of response are unclear. Furthermore, self-completed reporting has limitations when it comes to determining the effective use of sunscreen (Julian *et al.*, 2023).

6.4 Future studies

The following studies are proposed for a better understanding of solar UVR exposure.

Proposed study 1

This thesis is the first to quantify the occupational solar UVR of outdoor opencast diamond mineworkers. Because the findings from this thesis cannot be extrapolated to other mining environments, measurements over a longer period, with larger sample sizes, in more mining operations, should be conducted.

Proposed study 2

The overall lack of solar UVR exposure measurement studies in Southern Africa was identified in this thesis. Thus, solar UVR exposure measurements with determination of skin phototypes, evaluation of the effectiveness of clothing in protecting the skin, and evaluation of knowledge of photoprotective measures and attitudes, and behaviours related to the use of photoprotective measures should be extended to

other opencast mining operations, occupations such as construction and gardeners in African countries.

Proposed study 3

Hu *et al.* (2010) investigated diurnal variations in exposure at the different body sites. This was achieved using Solar Sensor UV attached to different areas of the rotating mannequin with readings taken every 30 minutes. The mining operations should conduct similar type of studies that may be conducted using PSF badges, or other electronic dosimeters. Wearable photoswitches for colorimetric dosimeters have been reported to have the potential to offer dependable, sensitive, and offer easier access to exposure information on which informed decisions can be made (Blackwell *et al.*, 2024).

Proposed study 4

The level of education was shown to be a predictor of knowledge, attitudes, and behaviours towards solar UVR exposure and related use of photoprotective measures. This implies that sun safety education tailored to diverse levels of education is required. However, findings from one study showed that training on its own does not guarantee changes in attitudes and behaviours (Houdmont *et al.*, 2016), while improvements in attitudes and behaviours were reported after training in another study (Rye *et al.*, 2014). Studies in which implementation of training programs are followed by assessment of knowledge, attitudes and behaviours using validated questionnaires (Rye *et al.*, 2014) are suggested.

Proposed study 5

The poor use of photoprotective measures such as sunscreen and sunglasses were reported in Chapter 5 of this thesis. The Namibian outdoor opencast mineworkers reported unaffordability and lack of time for application as justification for poor use of sunscreen. An in-depth study that investigates barriers to the use of all types of available photoprotective measures should be conducted.

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SUPPLEMENT A: Author guidelines for Annals of Work Exposure and Health

(Excerpt from journal website, https://academic.oup.com/annweh/pages/author_guidelines)

The Annals of Work Exposures and Health is an international journal presenting peer-reviewed science dedicated to the assessment and control of hazardous exposures and their health impacts in the workplace.

Language: Manuscripts must be in English, and authors should try to write in a way which is simple and clear. British or American styles and spelling may be used, but should be used consistently, and words or phrases which might be unclear in other parts of the world should be avoided or clearly explained.

Brevity: The necessary length of a paper depends on the subject, but any submission must be as brief as possible consistent with clarity. The number of words, excluding the abstract, references, tables and figures, must be stated at the time of submission.

Title, Abstract and Keywords: Titles should be constructed to succinctly describe the major issue or question examined by the paper and should not assert the research findings as a truth. Words and phrases in the title are used to index the article in databases, so keywords should not duplicate words in the title. Ensure that the abstract contains the most important terms for aid in indexing and searching.

Authors: All names and affiliations of authors should be clearly stated at the beginning of the paper. For full details see Publication Ethics section (Authorship).

What's Important About This Paper: FOR ORIGINAL RESEARCH PAPERS, REVIEW ARTICLES AND SHORT COMMUNICATIONS ONLY: We ask you to state, in 3-5 sentences, why the article you are submitting is important. This is an opportunity for you to demonstrate the potential impact of your paper, and it may also assist in subsequent promotion of the work.

Structure of Paper: Papers should generally conform to the pattern: Introduction, Methods, Results, Discussion, and Conclusions, unless these are clearly inappropriate.

Figures: Figures include photographs, diagrams and charts and may be shown in full colour at no additional cost. Figures should be numbered consecutively and given a suitable, informative caption.

Tables

Tables should be numbered consecutively and given a suitable, informative caption. In the first submission, tables can be incorporated into the text or at the end of the manuscript, but in the revised version each table should be presented on a separate page. Footnotes to tables should be provided below the table and should be referred to by superscript lowercase letters.

References

The accuracy of references is the responsibility of the author. This journal follows CSE Scientific Style and Format 8th edition with name-year references:

<https://www.scientificstyleandformat.org/Home.html>. All references should be listed in alphabetical order and all author names listed unless there are more than ten authors.

Examples:

Journal Article: Smart N, Fang ZY, Marwick TH. A practical guide to exercise training for heart failure patients. *J Card Fail.* 2003;9(1):49–52.





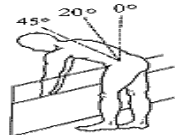

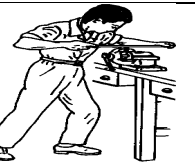


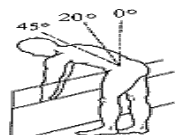
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SUPPLEMENT B: Questionnaire

Participant questionnaire on occupational and non-occupational exposure to the sun (solar ultraviolet radiation) and practices

Part 1: BIOGRAPHICAL DATA					
<i>This section requires you to fill in your personal details that will be used to identify your questionnaire and provide individual feedback.</i>					
Work site				Date	
Participant number					
Gender	Male	Female	Age		
Ethnicity	White	Black	Indian	Coloured	
Job category:					
What is your highest level of education?					
No schooling	Grade 1-3	Grade 4-6	Grade 7-9	Grade 10-12	Tertiary education
Do you know your HIV status?					
Negative	Positive	I do not know	I do not want to disclose		
PART 2: PREVIOUS OUTDOOR OCCUPATION (JOB):					
<i>Question A1 to A7 refer to information about an outdoor job you held in the past. Make a cross (X) on the box with the answer that applies to you.</i>					
A1) Did you work in an outdoor occupation (job) in the past?					
No				Yes	
If your answer to A1 above is Yes, then continue with Question A2 to A7, otherwise go to Question A8.					
A2) How many years did you work in the past outdoor job?					
A3) How many days of the week did you work in your previous outdoor job?					
A4) How many hours a day did you work outside in your previous job?					
A5) Which posture(s) did you adopt the most in your previous job? (Tick all that apply to you)					
Sitting	Standing	Lying down	Crouching	Bending forward	
					
A6) Did you receive sun safety education and training in your previous job?					
I did not receive training	Once	Two times	More than two times		
A7) If you received sun safety education and training, which of the following aspects did your training cover in your previous outdoor job? (Make a cross (X) on all that apply to you)					
How to use sunscreen	Importance of covering your skin with long sleeved clothes	Importance of eye protection	Importance of staying in the shade	Importance of skin checks	
PART 3: CURRENT OUTDOOR OCCUPATION (JOB)					
<i>The following questions refer to the job you hold now. Write in the number for Question A8 to A15.</i>					
A8) How many years have you been in the outdoor job you hold now?					
A9) How many days a week do you work in the outdoor job you hold now?					
A10) How many hours a day do you work outside in the outdoor job you hold now?					
For question A11 to A15 you are required to make a cross (X) on the box with the answer that applies to you.					
A11) Which body positions (postures) do you adopt the most in the job you hold now? (Make a (X) cross on all that apply to you)					
Sitting	Standing	Lying down	Crouching	Bending forward	
					
A12) Do you use welding equipment during any of your work activities in the job you hold now?					

Never	Sometimes	Always				
A13) Did you receive sun safety education and training in job you hold now?						
I did not receive training	Once	Two times	More than two times			
A14) if you did receive training, which of the following aspects did the training in your current job cover? (tick all applicable)						
How to use sunscreen	Importance of covering your skin with long sleeved clothes	Importance of eye-protection	Importance of staying in the shade whenever possible	Importance of skin checks	Health effects of prolonged exposure to the sun	
A15) Do you work in the shade in the job you hold now?		No	Yes			
A16) If your answer to A15 is yes, write down the number of hours you work in the shade every day in the job you hold now?						
PART 4: PERSONAL PRACTICES DURING WORKING HOURS						
Questions A17 to A27 refer to your practices during working hours in the job you hold now.						
A17) In which type of area do you spend your breaks (lunch and tea times)? Make a cross (X) on all that apply to you						
Sunny (Not covered)	Shady (Covered)	Semi-shady (Tree)	I move around between different types of areas			
A18) Do you apply sunscreen while working in the sun?						
Never	Sometimes	Always				
A19) If you do apply sunscreen, on which parts of your body do you apply sunscreen while in the sun? Please choose all that apply to you.						
Face	Neck	Arms	Legs			
A20) How often do you reapply sunscreen when outdoors during working hours?						
Never	Every 5 hours	Every 2 hours	Every 1 hour	More than once per hour		
A21) How often do you wear a hat when outdoors during working hours?						
Never	Sometimes	Always				
A22) Indicate the type(s) of hat you wear when outdoors during working hours? (Mark all that apply to you with an X)						
						
A23) How often do you wear clothes that cover your whole-body including arms and legs during working hours?						
Never	Sometimes	Always				
A24) Which type of clothes do you wear most of the time during working hours? (Mark all that apply to you with an X)						
T-shirt		Shirt		Coveralls		
Short sleeve	Long sleeve	Short sleeve	Long sleeve	No sleeves, long trousers	Short sleeves, long trousers	Long sleeves, long trousers
						
A25) How often would you wear less clothing so that you are able to get some sun on your skin while at work?						
Never	Sometimes	Always				
A26) How often do you wear eye-protection (sunglasses) when outdoors during working hours?						
Never	Sometimes	Always				
A27) Mark the type of eye-protection you wear during working hours. Otherwise go to A28.						
Non-Prescription sunglasses with UVA and UVB lenses	Prescription sunglasses with tinted lenses	Prescription sunglasses with plain lenses (no tinting)	Goggles	Wrap-around goggles		



PERSONAL PRACTICES DURING OFF-DUTY TIME
The following questions (A28 to A40) refer to your practices during your off-duty time. Make a cross (X) on the box with the answer that applies to you.

A28) Do you spend time in the sun during your off-duty time?

Never	Sometimes	Always
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A29) How many hours do you spend in the sun per day during your off-duty time?

A30) Do you apply sunscreen when outdoors during your off-duty time?

Never	Sometimes	Always
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A31) On which parts of your body do you apply sunscreen when outdoors during your off-duty time? Please mark all that apply to you with an X.

Face	Neck	Arms	Legs
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A32) How often do you reapply your sunscreen when outdoors during your personal time?

Never	Sometimes	Always
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A33) If you do reapply sunscreen, how many hours do you wait before you reapply during your off-duty time?

A34) What is the Sun Protection Factor (SPF) of the sunscreen you use during your off-duty time?

I do not know	15	Greater than 30	Greater than 50
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A35) How often do you wear clothes that cover your whole-body including arms and legs when outdoors during off-duty time?

Never	Sometimes	Always
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A36) How often would you wear less clothing so that you are able to get some sun on your skin when outdoors during your off-duty time?

Never	Sometimes	Always
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A37) Which type of clothing do you wear when outdoors during your off-duty time? Mark all that apply to you with an X

T-shirt		Shirt		Coveralls		
Short sleeve	Long sleeve	Short sleeve	Long sleeve	Long sleeves, long trousers	No sleeves, long trousers	Short sleeves, long trousers
						






A38) Which type(s) of hat(s) do you wear during your off-duty time? Mark all that apply to you with an X

Never							
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A39) How often do you wear eye-protection (sunglasses) when outdoors in your off-duty time?

Never	Sometimes	Always
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A40) if you wear eye protection, which type of eye-protection do you wear when outdoors in your off-duty time

Non-Prescription sunglasses with UVA and UVB and tinted lenses	Non-prescription sunglasses with UVA and UVB lenses	Prescription lenses with no tinting	Goggles	Wrap-around goggles
				

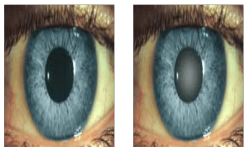
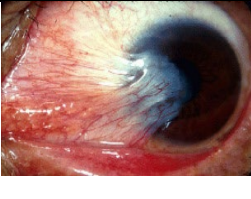


PERSONAL HEALTH HISTORY RELATED TO SUN EXPOSURE

The following questions (A41 to A42) refer to any health effects that you may have experienced due to exposure to the sun. Make a cross (X) on the box with the answer that applies to you.

A41) Have you ever suffered from any skin conditions?	No	Yes	I do not know
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Describe (if you have suffered from a skin condition)

A42) Have you ever suffered from an eye ailment that is associated with exposure to the sun such as cataracts, (a medical condition in which the lens of the eye becomes progressively opaque, resulting in blurred vision) pterygium (a growth of pink, fleshy tissue on the conjunctiva, the clear tissue that lines your eyelids and covers your eyeball), squamous cell carcinoma of the eyelid or basal cell carcinoma of the eyelid (cancer of the eye lids)?

I do not know	Cataract	Pterygium	Squamous cell carcinoma of eye lid	Basal cell carcinoma of the eye lid
				

Annexure B: Knowledge and attitudes of outdoor workers regarding the sun

PART 1: KNOWLEDGE ABOUT THE SUN

Question B1 and B2 refer to your knowledge about the sun. Make a cross (X) on the box with the answer that applies to you.

B1) Do you know what ultraviolet radiation is?	No	Yes	
B2) What time of the day is the sun the hottest?			
I do not know	9:00 am - 12:00 pm	10:00 – 4:00 pm	2:00 pm – 5:00 pm

PART 2: KNOWLEDGE REGARDING HEALTH EFFECTS OF EXPOSURE TO THE SUN

Questions B3 to B15 refer to your knowledge regarding the health effects of exposure to the sun. Make a cross (X) on the box with the answer that applies to you.














B3) It is good to spend a little time in the sun every day	No	Yes	I do not know
B4) Being exposed to the sun for longer periods is the most important risk factor for skin cancer	No	Yes	I do not know
B5) What do you use to repair your skin when it has been burned by the sun? Name all methods you use.			
I allow my skin to heal on its own	I use other method(s). Describe:		






B6) Which vitamin is synthesized by exposure to the sun?								
I do not know	Vitamin A	Vitamin B	Vitamin C	Vitamin D	Vitamin E			
B7) Do you know anyone who became sick due to excessive exposure to sun?				No	Yes			
B8) What are the health effects of excessive exposure to the sun? (Choose all that are correct)								
Skin cancer	Stomach ache	Sunburn	Low blood pressure	Skin aging				
B9) What are the effects of exposure to sun on the eyes? (Choose all that you think are correct)								
The sun does not affect the eyes	Irritation	Cataracts	Blindness	It causes diseases of the eyelid	I do not know			
B10) Can sunburn cause permanent damage to the skin?								
No		Yes		I do not know				
B11) Do people with darker skin colour suffer from skin cancer?								
No		Yes		I do not know				
B12) Do people with darker skin suffer from cataracts?								
No		Yes		I do not know				
B13) Do people with darker skin burn as easily as people with lighter skin?								
No		Yes		I do not know				
B14) Have you been exposed to information about the health effects of sun exposure?								
I have not been exposed to information about health effects of the sun		No		Yes				
B15) If yes, where have you been exposed to information about the health effects of sun? (Choose all that apply to you)								
School	Family	Friends	TV	Internet	Print media	Radio	Clinic or Doctor	Traditional healer
PART 3: KNOWLEDGE REGARDING SUN PROTECTION MEASURES								
<i>The following section (B16 to B 21) refers to your knowledge regarding the different protection measures. Make a cross (X) on the box with the answer that applies to you.</i>								
B16) Do you know the meaning of the Ultraviolet index (UVI)?								
No		Yes		I have heard of it, but I do not know what it means				
B17) Do you know what a sunscreen's sun protection factor means?								
No		Yes		I have heard of it, but I do not know what it means				
B18) Do people with lighter colour skin have to use sunscreen?								
No		Yes		I do not know				
B19) Do people with dark skin colour have to use sunscreen?								
No		Yes		I do not know				
B20) What type of clothing prevents more of the sun from reaching the skin surface?								
Lighter coloured clothing			Darker coloured clothing		Both of these options		I do not know	

<i>B21) Where have you been exposed to information about the sun protection measures? (Choose all that are correct)</i>									
I have not been exposed to information about sun protection measures	Family	Friends	TV	Internet	Print media	Radio	Clinic or Doctor	Traditional healer	
PART 4: ATTITUDES REGARDING EXPOSURE TO SUN OR UVR <i>The following section (B22 to B31) refers to your attitude regarding exposure to the sun. Make a cross (X) on the box with the answer that applies to you.</i>									
<i>B22) Do you worry about exposure to sun when working outside</i>						<input type="radio"/>	Yes		
<i>B23) Do you look at the ultraviolet index (UVI) when planning to go outside?</i>						<input type="radio"/>	Yes		
<i>B24) Would you change your plans to go outside if you knew that the UVI level was?</i>						<input type="radio"/>	Yes		
<i>B25) I do not think that I spend too much time in the sun.</i>						<input type="radio"/>	Yes		
<i>B26) I like my skin to look tanned or darker.</i>						<input type="radio"/>	Yes		
<i>B27) I stay for long periods of time in the sun to look more tanned or to darken my skin.</i>						<input type="radio"/>	Yes		
<i>B28) Somebody that is tanned or has a darker skin is more attractive.</i>						<input type="radio"/>	Yes		
<i>B29) Somebody with freckles or sunspots is less attractive.</i>						<input type="radio"/>	Yes		
<i>B30) I enjoy spending time in the sun.</i>						<input type="radio"/>	Yes		
<i>B31) I have recently changed my sun exposure habits.</i>						<input type="radio"/>	Yes		
<i>B31) I think I am at risk of skin cancer.</i>									
No			Yes			I do not know			
PART 5: ATTITUDES REGARDING SUN PROTECTION MEASURES <i>The following section (B32 to B44) refers to your attitude regarding the different protection measures. Make a cross (X) on the box with the answer that applies to you.</i>									
<i>B32) Sun protection is important while driving.</i>						<input type="radio"/>	No	<input type="radio"/>	Yes
<i>B33) Is it important to work in the shade when it is hot?</i>									
No			Yes			I do not know			
<i>B34) Why do you work in the shade?</i>									
I do not work in the shade		Somebody tells me to work there		It is cooler		It protects me from sunburn			
<i>B35) Is it important to protect skin with clothing?</i>									
No			Yes			I do not know			
<i>B36) Why do you wear long sleeved clothing when working outside in the sun?</i>									
I do not wear long sleeved clothing		Somebody tells me to wear long sleeved clothing		I look good in long sleeved clothing		It protects my skin from being burned		I have no reason	
<i>B37) Is it important to wear sunglasses to protect eyes from the sun?</i>									
No			Yes			I do not know			
<i>B38) Why do you use wear sunglasses when outside in the sun?</i>									
I do not wear sunglasses		Somebody tells me to wear it		I look good in sunglasses		It protects my eyes from being damaged		I have no reason	
<i>B39) Is it important to wear a hat when you are outside in the sun?</i>									

No	Yes	I do not know
B40) Why do you wear a hat when you are outside in the sun?		
I do not wear a hat	Somebody tells me to wear it	I look good in a hat It protects my head and face from being burned
B41) Is it important to wear sunscreen?		
No	Yes	I do not know
B42) Do you apply sunscreen when outside in the sun?		
I do not apply sunscreen	Somebody told me to apply sunscreen	Sunscreen protects me against sunburn
B43) Sunscreen is too expensive		No Yes
B44) I do not have time to apply sunscreen		No Yes

Annexure C: Work-site specific questionnaire to be filled in by operations manager and researcher

Mining operation Code							
Date							
Total number of outdoor workers							
Categories of outdoor workers							
Duration of breaks (minutes)		Morning	Lunch	Afternoon			
WORKPLACE PROVISION OF SUN PROTECTION MEASURES							
<i>The following section (C1 to C9) refers to sun protection measures that are provided by the company to outdoor workers. Make a cross (X) on the box with the answer that applies to your company.</i>							
C1) Does your company provide sunscreen to outdoor workers?							
The company does not issue sunscreen to workers	SPF <10	SPF 15	SPF30 – 50	SPF >50			
C2) How often is sunscreen given to outdoor workers?							
The company does not give sunscreen to workers	Once a month	Once in 3 months	Once in 6 months	Once a year			
C3) Which type of hat does the company issue to outdoor workers? (Mark all applicable options)							
The company does not issue hats to outdoor workers							
C4) Which type of clothing does the company issue to outdoor workers? (Mark all applicable options)							
The company does not issue clothing to outdoor workers	Short sleeve T-shirt	Long sleeve T-shirt	Short sleeve shirt	Long sleeve shirt	Long sleeve, long trousers coveralls	Sleeveless, long trousers coveralls	Short sleeve, long trousers coveralls
							
C5) Which type of eye protection does the company issue to outdoor workers? (Mark all applicable options)							
The company does not issue eye protection	Prescription sunglasses with UVA and UVB lenses	Non-prescription sunglasses with tinting	Non-prescription sunglasses with no tinting	Goggles	Wrap-around glasses		

					
C6) Are there any work activities performed in the shade?				No	Yes
C7) Is there shade provided for use by the outdoor workers during breaks?				No	Yes
Description of shade:					
C8) How often has your company offered sun safety education and training to outdoor workers in the last 12 months?					
Never		Once		Two times	
				More than 2 times	
C9) Which of the following aspects did your company's sun safety education and training cover (tick all applicable)					
Not applicable	How to use sunscreen	Importance of covering your skin with long sleeved clothes	Importance of eye protection	Importance of staying under shade	Importance of skin checks
SURROUNDING STRUCTURES (OBSERVATIONS MADE BY RESEARCHER)					
C10) Type of buildings		Brick	Concrete		Corrugated iron
C11) Type of roof		Concrete slab	Tile	Corrugated (shiny) iron	Thatch
C12) Distance between workers and nearest building(s) in metres					
C13) Type of horizontal surface (ambient measurements)					
Grass	Paving	Soil	Sand	Concrete	

SUPPLEMENT C: Ethics approval certificates
C1. Republic of Namibia Ethics approval certificate



REPUBLIC OF NAMIBIA

Ministry of Health and Social Services

Private Bag 13198
Windhoek
Namibia

Ministerial Building
Harvey Street
Windhoek

Tel: 061 – 2032150
Fax: 061 – 222558
Email: shimenghipangelwa71@gmail.com

OFFICE OF THE PERMANENT SECRETARY

Ref: 17/3/3 CR
Enquiries: Mr. J. Nghipangelwa

Date: 15 December 2017

Ms. Cynthia Ramotsehoa
North West University
P.O. Box X6001, Potchefstroom
South Africa

Dear Ms Ramotsehoa

RE: Occupational exposure of workers to solar ultraviolet radiation at selected opencast mining operations in Namibia and Chile.

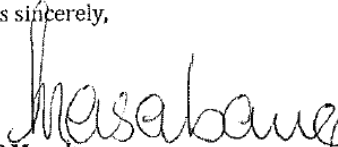
1. Reference is made to your application to conduct the above-mentioned study.
2. The proposal has been evaluated and found to have merit.
3. **Kindly be informed that permission to conduct the study has been granted under the following conditions:**
 - 3.1 The data to be collected must only be used for academic purposes;
 - 3.2 No other data should be collected other than the data stated in the proposal;
 - 3.3 Stipulated ethical considerations in the protocol related to the protection of Human Subjects' should be observed and adhered to, any violation thereof will lead to termination of the study at any stage;
 - 3.4 A quarterly report to be submitted to the Ministry's Research Unit;

3.5 Preliminary findings to be submitted upon completion of the study;

3.6 Final report to be submitted upon completion of the study;

3.7 Separate permission should be sought from the Ministry of Health and Social Services for the publication of the findings.

Yours sincerely,



Ms. P Masabane
Acting Permanent Secretary



"Your Health Our Concern"

C2. North-West University Health Research Ethics Committee (HREC) of the Faculty of Health Sciences approval certificate, amendment, and final monitoring report.



Private Bag X6001, Potchefstroom

South Africa 2520

Tel: 018 299-1111/2222

Web:

<http://www.nwu.ac.za>

**Faculty of Health Sciences Ethics Office
for
Research, Training and Support**

**Health Research Ethics Committee
(HREC)**

Tel: 018-285 2291

Email: Wayne.Towers@nwu.ac.za

6 March 2018

Prof FC Eloff
Occupational Hygiene
OHHRI

Dear Prof Eloff

**APPROVAL OF YOUR APPLICATION BY THE HEALTH RESEARCH
ETHICS COMMITTEE (HREC) OF THE FACULTY OF HEALTH
SCIENCES**

Ethics number: NWU-00031-17-A1

Kindly use the ethics reference number provided above in all future correspondence or documents submitted to the administrative assistant of the Health Research Ethics Committee (HREC) secretariat.

Study title: Occupational exposure of workers to solar ultraviolet radiation at selected opencast mining operations in Namibia and Chile.

Study leader: Prof FC Eloff

Student: MC Ramotsehoa - 10074031

Application type: Single study

Risk level: Minimal (monitoring report required annually)

You are kindly informed that your ethics approval application has been successful and fulfils all requirements for approval. Your study is approved for a year and may commence from 19/04/2017. It, however, requires specific conditions to be fulfilled during the progress of your study:

- a. Please provide the HREC with the permission letters from the appropriate governmental departments in Chile as well as from the mine at which the applicants will be undertaking the study, before the study can proceed in Chile.
- b. Please provide the HREC with copies of the ethics approval certificates from the appropriate research ethics authorities in Chile or proof that ethics approval is not required from such authorities, before the study can proceed in Chile.

As the study progresses the stipulated documents should be submitted to

EthicsHRECProcess@nwu.ac.za with a cover letter with a specific subject title indicating "Outstanding documents for approval: NWU-XXX-XXX." The letter should include the title of the approved study, the names of the researchers involved, that the documents are being submitted as part of the conditions of the approval set by the HREC, the nature of the document i.e. which condition is being fulfilled and any further explanation to clarify the submission.

The *e-mail*, to which you attach the documents that you send, should have a specific subject line indicating the nature of the submission, as well as the nature of the document being sent e.g. "Outstanding documents for approval: NWU-XXX-XXX." This submission will be handled via the expedited process.

Continuation of the study is dependent on receipt of the annual (or as otherwise stipulated) monitoring report and the concomitant issuing of a letter of continuation. A monitoring report should be submitted two months prior to the reporting dates as indicated i.e. annually for minimal risk studies, six-monthly for medium risk studies and three-monthly for high-risk studies, to ensure timely renewal of the study. A final report must be provided at completion of the study or the HREC, Faculty of Health Sciences must be notified if the study is temporarily suspended or terminated. The monitoring report template is obtainable from the Faculty of Health Sciences Ethics Office for Research, Training and Support at EthicsHRECMonitoring@nwu.ac.za. Annually, a number of studies may be randomly selected for an internal audit.

The HREC, Faculty of Health Sciences requires immediate reporting of any aspects that warrants a change of ethical approval. Any amendments, extensions or other modifications to the proposal or other associated documentation must be submitted to the HREC, Faculty of Health Sciences prior to implementing these changes. These requests should be submitted to Ethics-HRECApply@nwu.ac.za with a cover letter with a specific subject title indicating, "Amendment request: NWU-XXX-XXX". The letter should include the title of the

approved study, the names of the researchers involved, the nature of the amendment/s being made (indicating what changes have been made as well as where they have been made), which documents have been attached and any further explanation to clarify the amendment request being submitted. The amendments made should be indicated in **yellow highlight** in the amended documents. The *e-mail*, to which you attach the documents that you send, should have a specific subject line indicating that it is an amendment request as well as the nature of the amendment e.g. "Amendment request: NWU-XXX-XXX". This submission will be handled via the expedited process.

Any adverse/unexpected/unforeseen events or incidents must be reported on either an adverse event report form or incident report form to Ethics-HRECIncident-SAE@nwu.ac.za. The *e-mail*, to which you attach the documents that you send, should have a specific subject line indicating that it is a notification of a serious adverse event or incident in a specific project e.g. "SAE/Incident notification: NWU-XXX-XXX". Please note that the HREC, Faculty of Health Sciences has the prerogative and authority to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process.

The HREC, Faculty of Health Sciences complies with the South African National Health Act 61 (2003), the Regulations on Research with Human Participants (2014), the Ethics in Health Research: Principles, Structures and Processes (2015), the Belmont Report and the Declaration of Helsinki (2013).

We wish you the best as you conduct your research. If you have any questions or need further assistance, please contact the Faculty of Health Sciences Ethics Office for Research, Training and Support at Ethics-HRECApply@nwu.ac.za.

Yours sincerely



Prof Wayne Towers
HREC Chairperson



Prof Minrie Greeff
Ethics Office Head



Prof FC Eloff
Occupational hygiene
OHHRI

Private Bag X6001, Potchefstroom
South Africa 2520

Tel: 018 299-1111/2222
Web: <http://www.nwu.ac.za>

**Health Sciences Ethics Office for Research,
Training and Support**

**North-West University Health Research Ethics
Committee (NWU-HREC)**
Tel: 018-299 2092
Email: Wayne.Towers@nwu.ac.za

19 November 2021

Dear Prof Eloff

APPROVAL OF YOUR AMENDMENT REQUEST BY THE NORTH-WEST UNIVERSITY HEALTH RESEARCH ETHICS COMMITTEE (NWU-HREC) OF THE FACULTY OF HEALTH SCIENCES

Ethics number: NWU-00031-17-A1

Kindly use the ethics reference number provided above in all future correspondence or documents submitted to the administrative assistant of the North-West University Health Research Ethics Committee (NWU-HREC) secretariat.

Study title: Occupational exposure of workers to solar ultraviolet radiation at selected opencast mining operations in Namibia

Study leader/Researcher: Prof FC Eloff

Student: MC Ramotsehoa - 10074031

You are kindly informed that your amendment request (changes to research sites to be used) to the aforementioned project has been approved. Any future amendments to the proposal or other associated documentation must be submitted to the NWU-HREC, Faculty of Health Sciences, North-West University, prior to implementing these changes. These requests should be electronically submitted to Ethics-HRECApplies@nwu.ac.za, for review BEFORE approval can be provided, with a cover letter with a specific subject title indicating, "Amendment request: NWU-XXXXX-XX-XX". The letter should include the title of the approved study, the names of the researchers involved, the nature of the amendment/s being made (indicating what changes have been made as well as where they have been made), which documents have been attached and any further explanation to clarify the amendment request being submitted. The amendments made should be indicated in **yellow highlight** in the amended documents. The *e-mail*, to which you attach the documents that you send, should have a *specific subject line* indicating that it is an amendment request e.g. "Amendment request: NWU-XXXXX-XX-XX". This e-mail should indicate the nature of the amendment. This submission will be handled via the expedited process.

Please note: Due to the nature of the amendment i.e. (data will no longer be collected from the South American site and has already been collected from the Namibian site), this study will be able to proceed during the current alert level, following receipt of the approval letter. No additional COVID-19 restrictions have been placed on the study except that the researcher must ensure that before proceeding with the study that all research team members have reviewed the North-West University COVID-19 Occupational Health and Safety Standard Operating Procedure.

We wish you the best as you conduct your research. If you have any questions or need further assistance, please contact the Faculty of Health Sciences Ethics Office for Research, Training and Support at Ethics-HRECApplies@nwu.ac.za.

Yours sincerely

Digitally signed by
Prof Petra Bester
Date: 2021.11.23
11:11:25 +02'00'

Chairperson: NWU-HREC

Current details: (23239522) G:\My Drive\9. Research and Postgraduate Education\9.1.5.3 Letters Templates\9.1.5.4.1_Approval_letter_Amend_Rec_HREC.docm
30 April 2018

File reference: 9.1.5.4.1



Private Bag X6001, Potchefstroom South Africa 2520

Tel: +2718 299-1111/2222

Web: <http://www.nwu.ac.za>

**Faculty of Health Sciences Ethics Office for
Research, Training and Support**

Prof FC Eloff

OHHRI

Tel: 018 299 2092

Email: wayne.towers@nwu.ac.za

30 November 2023

Dear Prof Eloff

FEEDBACK ON NWU-HREC ANNUAL MONITORING REPORT: NWU-0003117-A1

We would like to thank you for submitting the annual monitoring report for your project entitled, "**Occupational exposure of workers to solar ultraviolet radiation at selected opencast mining operations in Namibia**", to the North-West University Health Research Ethics Committee (NWU-HREC) in a timely manner. Please find below the decision of the NWU-HREC regarding the continuation of your project.

Classification	Mark with X	Comment
Clarification		
Completion (Final report)		
Suspended		
Continuation	X	Date of next monitoring report: 30 November 2024
Termination		

Should you have any further queries, please feel free to contact Mr Buti Majola at your earliest convenience (E-mail: Ethics-HRECMonitoring@nwu.ac.za; Tel: 018 299 2197). We wish you well in your future endeavours. Yours sincerely

Chairperson: NWU-HREC

Do not type here

Current details: (24355305) G:\My Drive\9. Research and Postgraduate Education\9.1.5.5 HREC Monitoring\NWU-00031-17-A1\9.1.5.5.4_Cont_NWU-00031-17-A1_30-11-

2023.docm

30 November 2023

File reference: 9.1.5.5.4

Current details: G:\My Drive\Letters April 2018\9.1.5.5_RoP_Feedback_Letter_Template.docm 11 September 2018

SUPPLEMENT D: Informed consent form

<p>Health Research Ethics Committee</p> <p>Faculty of Health Sciences NORTH-WEST University (Potchefstroom Campus)</p> <p>2018 -03- 26</p> <p>HREC Stamp</p>
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NORTH-WEST UNIVERSITY[®]
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

**INFORMED CONSENT DOCUMENTATION FOR WORKERS AT SELECTED
OPENCAST MINING OPERATIONS IN NAMIBIA.**

***TITLE OF THE RESEARCH STUDY: Occupational exposure of workers to solar
ultraviolet radiation at selected opencast mining operations in Namibia.***

ETHICS REFERENCE NUMBERS: NWU-00031-17-A1

PRINCIPAL INVESTIGATOR: Prof FC Eloff

POST GRADUATE STUDENT: Ms MC Ramotsehoa

ADDRESS: OHHRI, Internal Box 144, NWU, Potchefstroom Campus.

CONTACT NUMBER: 018 299 2442

*We invite you to take part in a research study that forms part of my PhD in Occupational Hygiene. Please take some time to read the information presented here, which will explain the details of this study. Please ask the researcher or person explaining the research to you any questions about any part of this study that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research is about and how you might be involved. In addition, your participation is **entirely voluntary**, and you are free to say no to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part now.*

*This study has approval from the **Health Research Ethics Committee of the Faculty of Health Sciences of the North-West University (NWU-00031-17-S1)** and will be conducted according to the ethical guidelines and principles of Ethics in Health Research: Principles, Processes and Structures (DoH, 2015) and other international*

ethical guidelines applicable to this study. It might be necessary for the research ethics committee members or other relevant people to inspect the research records.

What is this research study all about?

- ▶ *This study will take place in Namibia at the Orange River Mines (Daberas and Sendelingsdrift) as well as at the Copper Mines (Los Bronces and Las Torti/as) in Chile. The purpose of the study is to measure the amount of ultraviolet radiation that workers at opencast mining operations receive from the sun. The study will involve the wearing of instruments that are able to measure ultraviolet radiation from the sun known as dosimeters. We will use two types of dosimeters in this study namely: polysulphone and electronic dosimeters. In addition, a determination of participants' skin type and melanin content will occur on areas of the body that are normally protected as well as those that are exposed to the sun. As part of the study, we will also evaluate the effectiveness of your clothing in blocking the sun. Lastly, participants will fill in two forms (questionnaires). The first form (questionnaire) will ask for information that relates to the history of outdoor occupation, behaviour during normal work and off-duty time, while the second form will collect information on the knowledge and attitudes of participants about working in the sun. Health researchers with training and experience in occupational hygiene measurements will carry out all activities in this study. The questionnaires will be available in Afrikaans and English for Namibia and Spanish and English for the Chilean participants. Help with filling-in of the questionnaires will be available when participants require it. At the end of the study, participants will receive a report on the findings of the study measurements and the recommendations on ways of protecting themselves against the effects of the sun.*
- ▶ *The total number of participants we require from each mining operation (site) will be between 25 (minimum) and 30 (maximum). This total number of participants will have a minimum of 20 and a maximum of 25 outdoor workers and a minimum of three and a maximum of five indoor (office) workers.*

Why have you been invited to participate?

- ▶ *We invite you to take part in this research study because the work you do involves activities that are carried out in an outdoor environment. You also fit the research because you work outside for a full shift.*
- ▶ *You will not be able to take part in this research if you spend half or part of your shift between indoors and outdoors as well as if you will be working night shift during the measurement period.*

What will be expected of you?

- ▶ *We expect you to wear five polysulphone dosimeter badges on the wrist of the dominant arm, nape (back) of the neck, shoulder (inside and outside clothing) and top of the head for a period of 4 days. You will also place one electronic dosimeter on the wrist of the dominant arm (the hand you use for writing). We will use adhesive tape or safety pin on clothing (for polysulphone) and Velcro arm or wrist strap (for electronic dosimeters) to attach the dosimeters on the different parts of the body. Both dosimeters will not interfere with your daily activities due to their small weights. We will show you how to put on the dosimeters before the start of the measurements and whenever it is necessary.*

You will place the dosimeters that have to go underneath clothing, in a private environment situated within your change rooms.

- ▶ *Additionally, we will ask you to be available for the determination of your skin types and melanin content once off during the measurement period at the volar forearm (inside of the upper arm) for classification of your natural colour.*
- ▶ *Furthermore, we will also measure the same skin variables on the exposed skin at the forehead, cheek, forearm (volar and dorsal side) and back of the hand. The aim of the skin measurement is to test the changes in your skin caused by working in the sun. The skin bioengineering instruments used for the skin measurements are not painful, they work only on the surface and the display of the readings occurs within a few seconds.*
- ▶ *We will also ask you to fill-in two questionnaires once off during one of the four days of measurements. The first questionnaire is about your occupational and non-occupational history of exposure to the sun/working outdoors as well as your behaviour (practices) such as the wearing of hats and protective clothing when outside in the sun. The second questionnaire will collect information on your knowledge and attitudes about the health effects of working outside in the sun. The two questionnaires will be available in languages other than English such as Afrikaans for the Namibian participants and Spanish for the Chilean participants.*

Will you gain anything from taking part in this research?

- ▶ *The first gain/benefit for you if you take part in this study is that you will receive information on how much ultraviolet radiation you receive from the sun, the grouping of your skin types and how to protect yourself from the sun.*
- ▶ *You will also gain knowledge about how effective the clothing you were on a regular basis in protecting against the effects of the sun.*
- ▶ *The other gain/benefit of the study is for all employees to learn how to protect themselves whenever they are outside in the sun. This knowledge is important not only for your job but is also relevant for your off-duty time.*
- ▶ *Your employer will also have a better understanding of the important aspects they will need to include during your training.*
- ▶ *Your families will also gain knowledge about the sun as you share the information with them.*

What are the risks in taking part in this study?

- ▶ *The risks to you in this study is that you may experience minimal physical discomfort when the adhesive tape is removed after the day's measurements and these will not last long and will not cause any serious skin damage. This will only happen when there is no clothing where we attach the dosimeters.*
- ▶ *You will also attach and remove the adhesive tape or Velcro straps yourselves to avoid discomfort.*
- ▶ *There are more gains for you in joining this study than there are risks.*

How will we protect your confidentiality and who will see your findings?

- ▶ *We will protect your personal findings from this study by using a code in the place of your name.*
- ▶ *We will respect your privacy by not forcing you to give out any information you do not feel comfortable giving out.*
- ▶ *All members of the research team will sign a confidentiality agreement to ensure that we treat your results as confidential.*
 - ▶ *Only the research team will be able to look at your findings. We will keep all study findings safe by locking hard copies in locked cupboards in the researchers' office and using passwords to protect all the data we store in the computer.*
- ▶ *When we have transferred the data from the dosimeters, we will delete it from the dosimeters immediately. We will then store the data for a period of 10 years after which we will destroy/delete it.*

What will happen with the findings or samples?

- ▶ *We will use the findings of this study in the future for the purpose of comparison.*
- ▶ *You will receive confidential mail about your measurements within six months after the end of the measurements. Your employer will receive general findings, which will not include any personal information at the same time.*
- ▶ *We will also provide a summary of the findings and recommendations in the form of a poster for display at your workplace for the benefit of everyone.*

Will you be paid to take part in this study and are there any additional costs for you?

- ▶ This study receives funding from Anglo American.
- ▶ No, you will not be paid to take part in the study because all the measurements will take place at work during your shift.
- ▶ There will thus be no costs involved for you, if you do take part in this study.

Is there anything else that you should know or do?

- ▶ You can contact Prof FC Eloff at +27 18 299 2442 or Ms MC Ramotsehoa at +27 18 299 2062 if you have any further questions or have any problems.
- ▶ You can also contact the Health Research Ethics Committee via Mrs Carolien van Zyl at 018 299 1206 or carolien.vanzyl@nwu.ac.za if you have any concerns that were not answered about the research or if you have complaints about the research.
- ▶ You will receive a copy of this information and a consent form for your own purposes.

Declaration by participant

By signing below, I agree to take part in the research study titled: Occupational exposure of workers to solar ultraviolet radiation at selected opencast mining operations in Namibia and Chile.

I declare that:

- I have read this information/it was explained to me by a trusted person in a language with which I am fluent and comfortable.
- The research was clearly explained to me.
- I have had a chance to ask questions to both the person getting the consent from me, as well as the researcher and all my questions have been answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be handled in a negative way if I do so.
- I may be asked to leave the study before it has finished, if the researcher feels it is in the best interest, or if I do not follow the study plan, as agreed to.

Signed at (place) On (date) 20....

Signature of participant

Signature of witness

Declaration by person obtaining consent

I (name) declare that:

- I clearly and in detail explained the information in this document to
- I did/did not use an interpreter.
- I encouraged him/her to ask questions and took adequate time to answer them.

- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I gave him/her time to discuss it with others if he/she wished to do so.

Signed at (place) on (date) 20....

Signature of person obtaining consent

Signature of witness

Declaration by researcher

I (name) Motsehoa Cynthia Ramotsehoa declare that:

- I had it explained by an Occupational Hygiene practitioner on site who I trained for this purpose.
- I did use an interpreter for the participants in Chile.
- I was available should he/she want to ask any further questions.
- The informed consent was obtained by an independent person.
- I am satisfied that he/she adequately understands all aspects of the research, as described above.
- I am satisfied that he/she had time to discuss it with others if he/she wished to do so.

Signed at (place) on (date) 20....

Signature of researcher

Signature of witness

SUPPLEMENT E: Language editing certificate



Venita de Kock

BA HONS. · PEG

☎ 084 588 5008

✉ venita.dekock@gmail.com

23 November 2024

LANGUAGE EDITING STATEMENT

I, Jannetje Levina De Kock hereby declare that the thesis

Occupational exposure of workers to solar ultraviolet radiation at selected
opencast mining operations in Namibia

by

Cynthia Ramotsehoa

Student Number: 10074031

for submission to the NWU.

- has been edited for language correctness and spelling.
- has been edited for consistency (repetition, long sentences, logical flow)

No changes have been made to the document's substance and structure (nature of academic content and argument in the discipline, chapter and section structure and headings, order and balance of content, referencing style and quality).

J L DE KOCK

SUPPLEMENT F: Turn-It-In summary report

10101268:MC_Ramotsehoa_combined.pdf

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