Digital Dosimeter-Based Risk Analysis of Squamous Cell Carcinoma in Lisbon and its Implications for Outdoor Workers Across Portugal

Epidemiology, Biostatistics, and Health Research

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Abstract

Introduction: Solar ultraviolet radiation (UVR) is one of the main causes of skin cancer, with squamous cell carcinoma (SCC) being particularly prevalent among outdoor workers due to chronic UVR exposure. Despite the increasing incidence of SCC in this group, cases remain under-reported and are not always classified as an occupational disease. Current guidelines for UVR exposure are established for the limit of 30 J/m^{-2} over and 8-hour day and they are implemented for both solar and artificial UVR (non-specific).

Main objective: To calculate the excess risk of SCC among outdoor workers in Lisbon based on measured solar UVR doses.

Methodology: A modelling study was conducted using data from a previous study that measured UVR exposure among outdoor workers in Lisbon. The relative risk (RR) of SCC was calculated using a formula developed by Milon *et al.*

Results and Discussion: Solar UVR exposure was consistently associated with an increased risk of SCC development by values ranging from 1% to 69%, in terms of individual UVR dose assessment. Despite some limitations, the novel approach and relevance of the study provide valuable insights for public health interventions aimed at reducing UVR exposure and SCC risk among outdoor workers.

Conclusion: Outdoor work is associated with an increased risk of SCC. However, the current model needs to be refined to improve the accuracy of risk assessment and to support the development of targeted prevention interventions.

Key words: Epidemiology of Occupational Exposures; Epidemiology of Chronic Diseases; Outdoor Workers; Squamous Cell Carcinoma (SCC); Solar Ultraviolet Radiation (UVR).

Resumo

Introdução: A radiação solar ultravioleta (RUV) é uma das principais causas de cancro da pele, sendo o carcinoma de células escamosas (CCE) prevalente entre os trabalhadores ao ar livre, devido à exposição crónica à RUV. Apesar do aumento da incidência do CCE, os casos continuam a ser sub-registados e nem sempre são classificados como doença profissional. As diretrizes atuais para a RUV são estabelecidas para o limite de 30 J/m-2 durante 8 horas diárias. No entanto, são tanto válidas para a RUV solar como para a artificial- inespecíficas.

Objetivo principal: Calcular o excesso de risco de CCE entre os trabalhadores ao ar livre, com base nas doses de RUV solar medidas.

Metodologia: Foi realizado um estudo de modelação utilizando dados de um estudo que mediu a exposição à RUV entre os trabalhadores ao ar livre em Lisboa. O risco relativo de CCE foi calculado utilizando uma fórmula desenvolvida por Milon *et al.*

Resultados e Discussão: A exposição solar à RUV foi consistentemente associada a um risco acrescido de desenvolver CCE, apresentando valores compreendidos entre 1% e 69%, em termos de dose de RUV individual. A abordagem inovadora e a relevância do estudo fornecem informações valiosas para intervenções de saúde pública destinadas a reduzir a exposição à RUV e o risco de CCE.

Conclusões: O trabalho ao ar livre está associado a um risco acrescido de CCE. O modelo atualmente existente precisa de ser aperfeiçoado para melhorar a precisão da avaliação do risco e o desenvolvimento de intervenções de prevenção específicas.

Palavras-chave: Epidemiologia de Exposições Ocupacionais; Epidemiologia de Doenças Crónicas; Trabalhadores ao ar livre; Carcinoma de Células Escamosas (CCE); Radiação Solar Ultravioleta.

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Introduction and Theoretical Framework

Solar ultraviolet (UV) radiation (UVR) is the primary causative factor for all types of skin cancer (1). Furthermore, UVR exposure is also responsible for other dermatological conditions, such as actinic keratosis (AK) and photoaging (2, 3, 4), and is involved in the pathogenesis of cataracts, pterygium, and other ocular diseases (3). Nevertheless, all individuals seem to deliberately expose themselves to UVR, whether during leisure activities or at work. This behaviour highlights the growing significance of UVR as a public health concern, underscoring the necessity for increased awareness and preventive measures (5,6).

Skin cancer is typically classified into two main categories: malignant melanoma and non-melanoma skin cancer (NMSC) (1, 6). Melanomas originate from melanocytes, which are melanin-producing neural crest-derived cells situated in the bottom layer of the epidermis (the *stratum basale*) (1, 6). In contrast, NMSCs develop gradually in the upper layer of the skin and are triggered by a combination of genetic and environmental factors (1, 6).

With regard to NMSC, the most prevalent are basal cell carcinomas (BCCs) and squamous cell carcinomas (SCCs), collectively accounting for approximately 99% of all NMSC cases (6). BCCs are associated with intermittent, acute UVR exposure on intermittently sun-exposed skin areas. In contrast, SCCs result from chronic, prolonged UVR exposure, which is more prevalent among outdoor workers who are exposed to solar UVR for extended periods of time (6-8). Therefore, participation in outdoor occupations is associated with higher incidences of this specific type of NMSC on exposed body sites (7, 8). Considering this and the purpose of this research, the focus of this research is on SCC.

In 2012, the International Agency for Research on Cancer (IARC) classified solar UVR as a Group 1 carcinogen, in recognition of the fact that previous research has demonstrated that approximately 65 to 90% of skin cancer cases can be attributed to solar UVR exposure, due to biological damage (9-11).

In Europe, between 29 and 51% of workers exposed to hazardous substances at work are exposed to UVR. This makes solar radiation the most frequent occupational carcinogen in many countries, particularly in regions where agriculture and fishing are common, for example, Portugal and Italy (12-14). As reported by the EU-OSHA (European Agency for Safety and Health at Work), 14.5 million outdoor workers in the European Union (EU) member states are potentially exposed to solar UVR for a minimum of 75% of their working time (14). Nevertheless, despite the recognition of the potentially harmful effects of solar UVR, the existent guidelines are oriented towards the prevention of immediate harms, such as photo-keratitis and sunburn (4, 15).

Furthermore, the use of the International Commission on Non-Ionizing Radiation Protection's (ICNIRP) exposure guideline (3) in an outdoor setting represents a significant challenge in terms of accurately assessing the correct UVR dose. Defined by the ICNIRP and by the American Conference of Governmental Industrial Hygienists (ACGIH), the current occupational limit set for UVR exposure is 30 J/m^2 per 8-hour shift for a worker exposed to UVR (3). Hence, these guidelines fail to consider the potential long-term effects of chronic UVR exposure (6), which is a significant issue in Europe, as the aforementioned limit applies also to artificial optical radiation (Directive, 2006/25/EC) (6). The absence of precise regulatory measures represents a significant concern for those engaged in outdoor work, underscoring the necessity for the implementation of comprehensive strategies and policies designed to protect this vulnerable and at-risk population.

It is imperative to gain an understanding of the risk of developing SCC in occupational settings and to provide relevant input towards standardising the measurement of solar UVR exposure in outdoor workers. Furthermore, it is also essential to ascertain the actual risk of SCC development and to acknowledge SCC as a potential occupational disease in this cluster of individuals (outdoor workers).

Squamous Cell Carcinoma Epidemiology: A Summary

NMSC represents a significant global health issue, with incidence rates demonstrating a persistent upward trajectory. As indicated in the GLOBOCAN 2022 report (17), there were approximately 20 million new cases of cancer in 2022. Of these cases, over 1.2 million were NMSC (excluding BCC) (17). Despite the relatively low mortality rate associated with this cancer type, particularly when diagnosed in the initial stages, NMSC results in significant morbidity, largely due to the limitations of available treatment options (8, 17). The choice of treatment depends on a number of factors, including the specific type and stage of the tumour, its size and location, the patient's preferences, and their overall health condition (8). The main treatment options include surgery, pharmacotherapy (use of medication), and radiation therapy, being the latter and the surgical excision of the affected skin area the preferred option. It should be noted, however, that these procedure/ treatments may result in disfigurement due to the destruction of surrounding tissues (4, 8, 18). The removal of tissue due to the presence of NMSC or the application of radiotherapy can contribute significantly to the morbidity associated with this disease. The adverse effects of these treatments on the patient's overall health are contingent upon the location and extent of tissue removal (18). For instance, if NMSC develops on visible areas such as the face or neck, surgical removal or radiotherapy may result in noticeable scarring or alterations in appearance, which could have an impact on a person's psychological well-being and quality of life. This highlights the increasing challenge that SCC presents for healthcare services (17, 18).

Notwithstanding the elevated incidence of NMSC (excluding BCC; henceforth referred to as SCC) diagnoses (17), there is concern about the lack of adequate reporting and management of this type of cancer. The incidence rates of SCC vary significantly across regions, with the highest rates observed in Australia/New Zealand and Northern America (19). However, the disease burden of NMSC is often underestimated due to under-reporting and limitations in data collection (17). This negligence has led to a lack of appropriate policies and measures for the management of NMSC (SCC) and the lack of targeted strategies to address risk factors and high-risk groups.

The prevalence of NMSC as a significant occupational hazard is becoming increasingly apparent, despite historical underreporting (20). In 2020, the World Cancer Research Fund classified NMSC as the fifth most common cancer globally, highlighting the urgent need for enhanced reporting and prevention measures, given the high number of unreported cases, with over a million diagnoses and a disregard for risk factors and protective measures. It is notable also that these numbers do not reflect or even mention AKs, which represent a dermatological condition that is indicative of prolonged exposure to UVR. Indeed, AKs have been identified as direct precursors of SCC (21, 22). Although the occurrence of SCC as a consequence of a solitary AK is uncommon, the risk of SCC developing in a patient with more than 10 AKs is estimated to be approximately 10 to 15% (22, 23).

Despite compelling epidemiological evidence and the fact that many outdoor occupational activities lead to UVR exposure that exceeds recommended limits, sun-induced skin cancer is not officially listed as an occupational disease by the International Labour Office or national authorities (24). This omission leads to a large underestimation of the burden of SCC as an occupational disease (4, 20). For instance, skin cancers constituted 1% of all occupationally recognised cancers in Europe in 2008. In Switzerland, where at least 4500 SCCs are diagnosed annually, only three cases of SCC were identified as occupational diseases between 2000 and 2007 (25, 26).

Undoubtedly, NMSC has a significant impact on public health due to its high incidence and morbidity rates, affecting wider society through reduced productivity and compromised quality of life. This emphasises the fundamental importance of early detection and implementation of prevention strategies for NMSC.

Squamous Cell Carcinoma Risk Assessment

In order to develop effective prevention strategies and guidelines, numerous researchers have sought to ascertain the risk of outdoor workers developing SCC over the course of their working lifetime. However, there is still a considerable discrepancy between the implementation of protective measures and the epidemiological evidence that is available, particularly given the elevated levels of solar UVR to which outdoor workers are exposed.

It is well established that individuals engaged in outdoor work are at risk of prolonged and excessive exposure to solar UVR, irrespective of ambient radiation levels (27). Solar UVR is classified into three distinct categories based on their wavelength, ranging from 100 to 400 nanometres (nm) (27, 28). Each category of UVR has a distinct set of biological effects and penetration abilities, as illustrated in Figure 1, which demonstrates the association between different patterns of UV exposure and diverse types of skin cancer (28). The first category, UVA (315-400nm), constitutes approximately 95% of the UV radiation that reaches Earth. It has the capacity to penetrate the dermis to a considerable depth, which can result in the immediate tanning, (premature) ageing of the skin and the formation of wrinkles (27, 28). The second category of UVR, classified as UVB (280-315 nm), has been demonstrated to have biological activity and primarily affects the surface layers of the skin. It causes delayed tanning and sunburn, accelerates the ageing process of the skin, and markedly elevates the risk of developing skin cancer. The majority of UVB radiation is filtered by the atmosphere (27, 28). UVC (100-280 nm), the third category, is the most dangerous type of UV radiation. However, it is fortunately

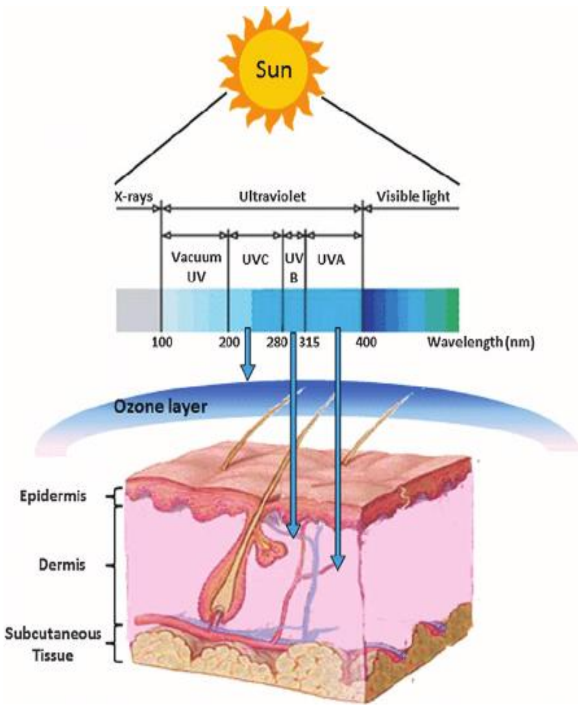

Figure 1 Summary of the different UV categories and their effect on the skin. Source: Reference 28

fully absorbed by the Earth's atmosphere, preventing it from reaching its surface (27, 28).

Wavelengths of a shorter nature are more harmful, yet penetrate the skin to a lesser depth, rendering individuals more susceptible to the development of NMSC types that develop in the upper layers of the skin (such as SCC) (27). This fact, when considered alongside the effects of repetitive tasks performed in a fixed posture or position, which is typically the case for outdoor workers due to the nature of their work, results in prolonged and repeated exposure to specific anatomical areas (29). For example, those engaged in gardening frequently adopt extended periods of kneeling or crouching while undertaking activities such as planting, weeding, or pruning. Prolonged postures involving the back and shoulders can result in excessive exposure to solar UVR, particularly in areas with limited or no shade (29, 30).

Considering the dearth of awareness concerning the prevalence of SCC among outdoor workers, as evidenced throughout this paper, numerous researchers have initiated studies with the objective of advancing public health and occupational policy. As previously stated, the current occupational limit for UVR exposure is 30 J/m² for an 8-hour shift for a worker exposed to UVR (31). This value is related to both artificial and solar UVR and it is generally converted and referred to as the Standard Erythemal Dose (SED), which represents a particular exposure dose that may cause erythema (skin reddening) in individuals with fair skin (phototype I and II, according to the Fitzpatrick Scale, a numerical classification schema for human skin colour). One SED is equivalent to an erythemal radiant exposure of 100 J/m² (31, 32). The use of this metric provides a standard measure that can be employed across different studies allowing comparisons, especially due to the fact that, in general, the accumulated UV dose is expressed in units of SEDs (31, 32). Hence, and adopting this metric, the occupational limit of SEDs should not exceed 1.33 SED per day, as recommended by the ICNIRP guidelines (32).

Building on this, many outdoor workers exceed the recommended occupational limits. For example, the solar UVR doses received by Romanian construction workers over the course of a seven-month occupational period have been observed to range from 165 SED to 453 SED (1,07 SED- 2,89 SED per day) (15). Similarly, Australian postal workers may have their hands exposed to over 15 SED for a period of six months per year- this value does not consider other body parts that may be exposed (33).

In the field of occupational health, the assessment of risk associated with the development of SCC is of paramount importance, as has been previously highlighted. A notable contribution to this field is the study by Milon *et al.* (34) which contains a formula that was developed for calculating the relative risk (RR) of developing SCC in an occupational context. This is defined as the calculation of the likelihood of a person developing SCC when exposed to solar UVR in a certain context, in comparison to a person who is not exposed in that same context.

A more detailed analysis of the formula developed by Milon *et al.* (34) shows that the model for calculating the RR of SCC was based on studies conducted by Schothorst *et al.* (35) and Slaper *et al.* (36). In these studies, SCC risk is presented as a function of age and cumulative UVR exposure and expressed by the following formula: $Risk\ (age) \propto age^{x} \times UV_{tot}^{b}$ (35, 36). The latter demonstrates that the risk of developing SCC is proportional to the age raised to the power of *x*, which represents an age-dependent factor that is not specified in the articles. This value is then multiplied by the total UV exposure, which is raised to the power of *b*, a biological amplification factor (34). The total UV exposure, UV_{tot}, incorporates occupational, leisure, and residential exposure and represents exposure based on country of residence, given that latitude and altitude alter UVR exposure and dose received.

Millon *et al.* (34) developed a more complex model in which the RR of developing SCC is expressed as follows:

$$RR_{\ age=T} = \frac{Risk_{B,T}}{Risk_{A,T}} = (\frac{UV_{tot,B}\ at\ age\ T}{UV_{tot,A}\ at\ age\ T})^{\beta}$$

In this context, the variables *A* and *B* represent two individuals of the same age who have been exposed to different cumulative UV doses, for two different individuals ($UV_{tot,A}$and $UV_{tot,B}$), *T* represents a specific age, and the ratio of cumulative UV doses is adjusted by the biological amplification factor b (34). The values of $UV_{tot,A}\ at\ age\ T$ and of $UV_{tot,B}\ at\ age\ T$ are calculated in a similar manner. The value of $UV_{tot,A}$ is calculated as the sum of the recreational UV exposure over the period from time T=0 to T=60. This suggests that UvtotA represents an individual who is primarily engaged in indoor work activities and who is only intermittently exposed to UVR during recreational activities and leisure time (34).

$$Cumulative\ UV\ dose\ A = UV_{tot,A}\ at\ age\ T = \sum_{T=0}^{60} UV_{tot} = \sum_{T=0}^{60} UV_{recr}$$

The calculation of $UV_{tot,B}$ entails the summation of three distinct categories of UVR exposure: (1) the total UVR exposure from time T=0 to T=60, (2) the UV exposure during occupational activities and lunchtime from time T to T+25, and (3) the UV exposure during recreational activities from time T=0 to T=60. However, for the purposes of this calculation, only values of y within the range of 25 to 35 are considered (34).

$$Cumulative\ UV\ dose\ B = UV_{tot,B}\ at\ age\ T =$$
$$= \sum_{T=0}^{60} UV_{tot} = \sum_{Y=T}^{T+25} (UV_{occ} + UV_{lunch}) + \sum_{T=0}^{60} UV_{recr}$$
$$\forall y \in [25,35]$$

The formula developed by Milon *et al.* employs the SimUVEx model for the estimation of UVR doses, which provides a comprehensive estimation/simulation of UV exposure (34). The use of this model/simulation was presented as a (minor) limitation of the RR estimation given that, while it was undoubtedly useful, it frequently lacked the degree of precision and accuracy required for the generation of reliable results (34). Considering this limitation, researchers began to investigate alternative, more direct measurement techniques, which resulted in the adoption of dosimeters, devices designed to measure the amount of UVR exposure. The use of disparate types of dosimeters was initially shown to result in inaccuracies in their readings, which in turn led to the distortion of UVR dose estimates and measurements. This highlighted the necessity for the utilisation of dosimeters that had undergone rigorous calibration and were operated in an appropriate manner, as instances of misuse and inadequate calibration have been identified as causes of discrepancies in recorded irradiance values (37, 38). Following these concerns, the GENESIS-UV system emerged as a superior alternative, offering enhanced accuracy and consistency in UV dose measurements (15). The system's design for decentralised long-term measurements using data-logging devices ensures ease of use and minimal disturbance to the wearer, which is crucial for obtaining reliable data over extended periods. Moreover, the GENESIS-UV system has an accelerometer that ensures that the devise is being used and has been subjected to rigorous testing in a comprehensive study encompassing over 250 occupations, resulting in the generation of over 3.7 billion data points (15). This extensive research has not only validated the system's precision but also made a significant contribution to the understanding of occupational UVR exposure and its associated risks (15). It can therefore be concluded that the GENESIS-UV system is to be regarded as a more reliable tool for assessing UVR exposure and aiding in the prevention of conditions such as SCC, which are critical for epidemiological studies and legislative efforts to combat skin cancer (15).

Relevance, Novelty and Aim of the Study

The value of this study lies in its comprehensive approach to understanding the cumulative impact of occupational solar UVR exposure on the development of SCC as an occupational disease. Building upon the foundational work of Milon *et al.* (34), which highlighted the necessity of utilizing actual exposure data for RR calculation in future studies, the present research makes a significant contribution to the field by employing the RR formula in conjunction with data collected directly by personal electronic dosimeters. This combination of data and methods provides a more accurate and objective measure of occupational UVR exposure and RR for developing SCC than is possible with self-reported or subjective estimates, which are often marred by recall bias and inconsistency.

Moreover, this study is notable for several reasons. Firstly, it is the first study in Portugal to utilise data from personal electronic dosimeters. Secondly, it encompasses a diverse range of professions. Thirdly, the formula developed by Milon et al. has not yet been employed in combination with UVR doses measured with dosimeters, as far as we are aware. This allows for a more comprehensive assessment of UVR exposure, associated risks and the relationship between the RR and different occupational groups. Furthermore, the results of this study have the potential to inform and enhance the implementation of solar UVR protective measures in the workplace, contributing to a comprehensive understanding of the exposure determinants necessary for the development of effective risk analysis and prevention strategies.

In addition, the findings of this research have significant implications for the economic burden placed on social security and healthcare systems worldwide due to occupational injuries and diseases. The empirical data presented in this study on the occupational contribution to UV exposure provides evidence to support to the recognition of SCC as an occupational disease. Furthermore, it underscores the importance of accurate risk assessment in safeguarding workers' health. In doing so, it aligns with global efforts to mitigate the economic impact of occupational health hazards and promotes the sustainable development of labour practices in harmony with workers' well-being and the Sustainable Development Goals 3 (Good Health and Well-being) and 8 (Decent Work and Economic Growth).

In consideration of the aforementioned evidence, the main objective of this paper is **to calculate the excess risk of developing SCC among outdoor workers in Lisbon, based on accurate solar UVR doses measured by digital dosimeters.**

As secondary objectives, we intend to (1) compare the UV doses and risk of developing NMSC (SCC) between different occupations and population groups, and (2) suggest public health and occupational health measures to be applied in the context of outdoor occupational environments.

Methodology

Study Design, Setting (Data Source) and Participants

To achieve the proposed objectives, a modelling study was conducted. In the fields of epidemiology and clinical research, modelling studies are of great importance for understanding and predicting the patterns of disease spread within populations. The insights derived from such models provide a scientific basis for strategies aimed at controlling and ultimately preventing the spread of diseases, in this case, of SCC.

In this case, a modelling study was conducted, utilising secondary data derived from a prospective observational study implemented within the Lisbon municipality (CML), the largest municipality in Portugal. The protocol for the aforementioned study has been published and is entitled "Digitally measuring solar ultraviolet radiation in outdoor workers: A study protocol for establishing the use of electronic personal dosimeters in Portugal" (39). The results of said study, designated the MEAOW study, are currently being submitted for publication as a supplement to this study.

In summary, the MEAOW study (39) aims to increase awareness of solar UVR-induced occupational skin cancers among the general public and policymakers in Lisbon and across Portugal. The study was developed on the premise that the RR associated with various patterns of solar UVR exposure differs between subtypes of keratinocyte cancer. These include intermittent or continuous exposure in either an occupational or leisure/recreational setting (more specifically, BCC or SCC, respectively, in regard to exposure patterns). This is significant due to the preventable nature of skin cancer, which can be achieved through the implementation of individual and collective protective measures and interventions designed to reduce exposure to solar UVR.

In the MEAOW study (39), personal dosimeters were employed, specifically through the GENESIS-UV system methodology (40, 41), which enables decentralised, long-term measurements using data-logging devices. The methodology was previously outlined in brief; however, it is worth reiterating certain aspects, as they warrant further attention.

The study observed individuals from six different occupations for approximately seven months, from 10 April to 31 October. During the aforementioned period, the participants were required to wear the GENESIS-UV personal electronic dosimeter, for the purpose of data collection, on their left upper arm. The device was secured with a specially developed holder that allowed for comfort and continuous and accurate data recording without disturbing the user. This was made possible by the utilisation of X2012-10 electronic data-logging dosimeters within the GENESIS-UV system, which enabled the measurement and recording of data over time. The dosimeters were programmed to measure UVA and UVB/C radiation at one-second intervals, with the data weighted using the erythema action spectrum directly on the device through specific filter combinations.

Subsequently, the data collected from each dosimeter was transferred to a tablet computer provided with the GENESIS-UV unit, thereby enabling the automatic reading

Figure 2 GENESIS-UV system and all the material associated with a single dosimeter

and transfer of the data.

To ensure compliance throughout the seven-month study period, only forty-nine dosimeters were assembled and distributed among the six occupational groups engaged in outdoor work: gravediggers, gardeners, pavers, asphalters, sanitation workers and sailors. These dosimeters were rotated within each group/ occupation over the course of the data collection period.

Participant eligibility (MEAOW Study)

The MEAOW study (39) included individuals who were engaged in outdoor work activities and employed by the CML. Specific outdoor occupations were identified and all individuals employed in these occupational groups under investigation were invited to participate in the study. This feature is of paramount importance to the present research, as it allows for a diverse evaluation of the occupational RR associated with the development SCC.

Outcome predicted

As previously stated, the primary objective of the present study is to calculate the excess risk of developing SCC among outdoor workers in Lisbon, based on precise solar UVR doses measured by digital dosimeters. This was accomplished through the utilisation of a formula developed by Milon *et al.* (34), which allows the calculation of the RR associated with the development of SCC in an occupational context. The application of the formula is explained below. Subsequently, the UVR doses and RR of developing SCC between different occupations and population groups were compared, with the objective of accurately suggesting public health and occupational health measures to be applied in the context of outdoor occupational environments.

Definition and Method for Measurement of Outcome- The Formula

Formula specifications and assumptions

Milon and colleagues (34) examined the influence of occupational solar UVR exposure on the risk of developing skin cancer with a particular focus on SCC, in individuals engaged in outdoor work. A numerical model was employed to estimate UV doses during work and lunch breaks, with the objective of assessing the risk of SCC through an epidemiological model. This numerical model was known as the SimUVEx model. The study demonstrated that regions of the body situated horizontally receive a greater degree of UV exposure than those positioned vertically. Moreover, the findings indicate that occupational exposure to the sun significantly increases the risk of developing SCC. The findings provide further evidence to support to the recognition of SCC as an occupational disease, given the significant contribution of occupational solar exposure to the overall lifetime UV dose.

1. *Milon's Exposure Model and Data Source*

In order to quantify the UV exposure experienced by outdoor workers, Milon et al. (34) employed the use of the SimUVEx model, a computer-based tool designed to assess the extent to which UVR from the sun reaches various regions of the body based on a number of factors, including posture and sun orientation. The model is dependent on meteorological data, which in this case was sourced from Switzerland and necessitates the input of variables such as direct and reflected sunlight, sun position, and scattered light. In order to assess the UV exposure experienced by workers with differing profiles (low, moderate, and high exposure) throughout the year, the researchers conducted 732 simulations, focusing on both daily and yearly doses. For further details, please consult the appendix.

Milon *et al.* (34), as previously mentioned, built upon the work of Schothorst *et al.* (35) and Slaper *et al.* (36) in which they estimated the impact of occupational outdoor activity and lunch break on the risk of SCC. In their model, the risk of SCC is expressed as a function of age and cumulative UV dose, with a proportional relationship between the two variables. The risk of developing the disease is proportional to the age of the subject and to the total amount of UVR exposure, including occupational, leisure, and residential exposure: $Risk\ (age) \propto age^{x} \times UV_{tot}^{b}$.

Milon *et al.* (34) further developed this model to create a framework for calculating the RR of SCC development. Their model was developed on the assumption that the probability of developing SCC increases with age and the total amount of UVR exposure a person receives from work, lunch breaks, and recreational activities. To facilitate a comparison of the risks involved, the researchers examined two hypothetical individuals of the same age (60 years old), one with a history of working outdoors and the other with an indoor occupation. A mathematical formula was used to express the RR of developing SCC between the two individuals.

The model assumes that the individual with an outdoor occupation was exposed to UVR at work and during lunch breaks over a 25-year period, whereas the individual with an indoor occupation only received UV exposure during recreational activities during the entire 60 years of their life (34). The total UV exposure for each individual was calculated using a combination of data from the SimUVEx model, which estimated UV exposure based on body position and sun orientation, and recreational exposure data from a large European study named Expolis (43, 44).

In conclusion, the model developed by Milon *et al.* assists in estimating the increased likelihood of developing SCC in an individual with a history of outdoor work in comparison to an individual with no such history, by considering the cumulative UV exposure over time. This is expressed by the following formula, which was also previously presented:

$$RR_{\ age=T} = \frac{Risk_{B,T}}{Risk_{A,T}} = \left(\frac{UV_{tot,B}\ at\ age\ T}{UV_{tot,A}\ at\ age\ T}\right)^{\beta} = \left(\frac{\sum_{Y=T}^{T+25}(UV_{occ} + UV_{lunch}) + \sum_{T=0}^{60} UV_{recr}}{\sum_{T=0}^{60} UV_{recr}}\right)^{\beta}$$

2. *Formula Assumptions*

Before applying the RR formula, certain things must be taken into consideration.

As previously stated, Milon et al. (34) employed data from a weather station in Switzerland to ascertain the UVR dose received by outdoor workers. Additionally, they utilised UVR data estimations from the Expolis study (44) for both outdoor and indoor workers, subsequently calculating the RR associated with SCC. Firstly, the RR model presented by Milon *et al.* (34) presents a value that is identified as β, which serves as an amplification factor. Milon *et al.* (34) assumed this value to be 2.5, which was derived from the study developed by Slaper *et al.* (1996) (36). This value was itself derived from two other (previous) studies. The source/ genesis of this value is unclear; however, for the sake of this paper, we also assumed it to be 2.5 in order to ensure the validity of our results, based on the RR model.

Furthermore, Milon et al. (34) emphasised the necessity and significance of calculating the RR of developing SCC using authentic UVR dose data. This calculation was the objective of the present study, and the data for this were derived from the MEAOW study (39), as previously mentioned. However, the MEAOW study (39) only measured UVR doses in occupational settings. No measurements were taken of the recreational UVR dose. Therefore, for the purposes of this study, the recreational UVR dose (and consequently the total UVR dose for indoor workers) was set as identical to those used by Milon et al. (34). These values were derived from the SimUVEx model and data from Expolis (43, 44). In addition, as previously stated, the RR formula necessitates the calculation of the cumulative UVR dose over the course of twenty-five and/or 60 years. The data collected during the MEAOW study (39) via GENESIS-UV dosimeters provided the UVR dose in joules per square metre (J/m^2) per half hour and per day. This data was then combined by dosimeter, to present an average UVR dose over the course of seven months. Based on the duration of the MEAOW project (7 months, excluding the winter season), representing an ambitious data plan, it was possible to extrapolate the existing data to the remaining five months of the year to estimate annual average UVR values as was required by the RR formula.

It is crucial to acknowledge that given the MEAOW study's duration, and this need to determine the average UVR dose in an accurate manner, it was necessary to determine which data was valid for the sake of being included in this research. A manual verification of the data was conducted on a daily basis, in order to ascertain its validity. This was accomplished by means of cross-referencing the data recorded by the dosimeters. The dosimeters were equipped with an accelerometer to ensure that the device was operational during the data collection process and that it was not left in an inactive state. Subsequently, the data underwent a process of triangulation, and an additional examination was conducted to ascertain the reasons behind the absence of valid data in certain dosimeters. Fortunately, it was established that the absence of certain data entries could be primarily attributed to the absence of device-related issues, suggesting that it could be attributed to human errors- more specifically, to errors in the utilisation of the dosimeter by the outdoor workers themselves. The GENESIS-UV team (which forms part of the MEAOW team) conducted this verification process in order to ensure the highest possible level of data validity. Subsequently, all data were classified manually and consequently organised according to the quality control criteria, and only those that had been validated were used for the present study.

Furthermore, it is also important to keep in mind that, since the MEAOW study (39) measured occupational UVR doses, one workday was defined as eight hours of work, given that outdoor workers typically take their lunch outdoors. Additionally, the annual UVR dose was calculated on the basis of the assumption that each worker in Portugal would take 22 days of vacation in a given year and that a working week is composed of five days (two days off per week). This entailed that, throughout the year, 52 "weekends" (104 days) were excluded from the calculation of the cumulative UVR dose corresponding to a year of outdoor work (one year of work was considered to be made up of 239 days). These values were converted to the SED, with the understanding that 1 SED is equivalent to 100 J/m², as previously stated (31, 32). The results of these calculations are presented in Table 2. It is important to note that each worker contributed differently to the data collection, particularly given that not all outdoor workers who participated in the MEAOW study (39) had a dosimeter for themselves. Moreover, there were no missing values for the purpose of the RR calculation as the requisite annual data was obtained from previously gathered and treated data.

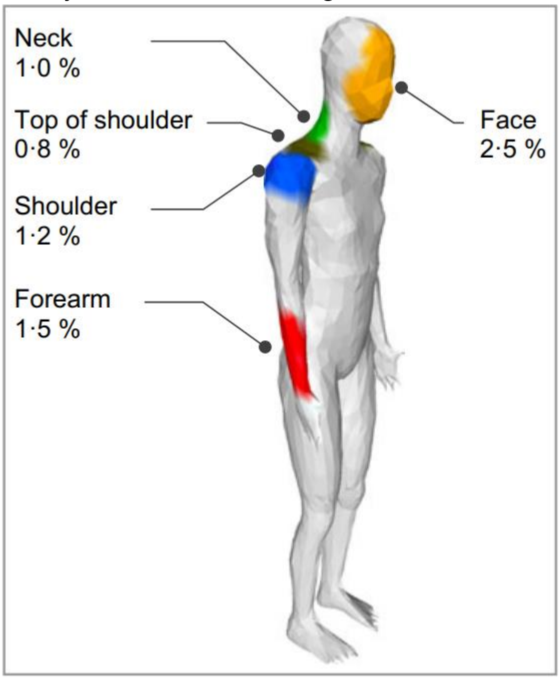

Figure 3 View of the numeric manikin and location of the anatomical sites investigated. The relative surface area of each site is expressed as a percentage of the total body surface area (about 2 m2). Source: Reference 34

Finally, in accordance with Milon et al. (34) and the SIMUVEx model, UVR exposure varies according to the orientation of the body parts. Horizontally oriented areas, such as the shoulders, receive more UVR than vertically oriented areas, such as the legs, due to direct sun exposure during peak sunlight hours. For example, the upper shoulders can receive 2 to 2.5 times more radiation than the legs. Outdoor workers typically wear trousers and T-shirts, exposing their shoulders and upper body to the sun, even in cooler weather, given Lisbon's average temperature of 15.5°C, based on data from the Portuguese Institute of the Sea and Atmosphere (IPMA). This means that although the body has a surface area of about 2 m², only about 6.2% (0.124 m²) is exposed to sunlight during working hours. This factor must be taken into account when assessing the risk of

SCC development. In the MEAOW study, the device was always used on the left upper arm.

Method for Measurement of the Outcome and Definition of the Outcome-Variables and Outcome

The data set derived from personal electronic dosimeters was employed in the present study with the aim of establishing a correlation between different levels of solar UVR and exposure patterns and the likelihood of developing SCC. This was conducted in accordance with the formula developed and published for this purpose by Millon *et al.* It can therefore be stated that the RR calculations were based on assumptions derived from previous research. Despite the utilisation of varying data inputs, the outcomes were attained via the same methodology and following the same steps as the RR formula developed by Milon *et al.* to maintain its validity. Consequently, the result is a single endpoint that focuses on the probability of a specific event, namely, the development of SCC.

The formula for RR calculation integrated predictors such as the UV dose and age, as well as an amplification factor that was defined on the basis that the risk of developing SCC is proportional to age and (cumulative) UV dose.

The outcome of this research consisted merely of a prediction of SCC development; thus, a separate longitudinal follow-up study will be conducted in the future to diagnose SCC and/or skin lesions in the participants of the MEAOW study, who contributed data for this study. This will entail the performance of clinical examinations with the objective of identifying any skin lesions. The results of these assessments will be compared with the predictions made in this study to evaluate the accuracy of the RR model.

Remaining Statistical Methods Employed and Additional Relevant Information

Software for outcome calculation and data preparation

The calculation of the outcome and intermediate data was performed using the R Studio and Microsoft Excel software.

Missing data

Despite having been previously considered, it remains pertinent to address the theme of "missing data" in greater detail. Insufficient quantities of dosimeters were made available in the MEAOW study, resulting in not all participants having a personal dosimeter and, consequently, using them for different amounts of time. This meant that not all participants were able to contribute equally to the study in terms of data. This issue has already been addressed in the methodology section above and it is not a problem since the objective of the study was to determine the occupational exposure doses of the six specific occupations. Despite these restraints, the use of dosimeters has been found to be appropriate in several studies, including one of the largest of its kind in Europe, which reinforces the importance of its findings (2, 40).

Furthermore, as previously indicated, the MEAOW study (39) spanned a period of seven months. This enabled the average UVR dose to be extrapolated from the seven-month data set to a year of data collection. The mean value derived from the seven-month period constituted the complete set of valid data entries. It should be emphasized that there were fewer dosimeters than participants, with the aim of enhancing compliance in the data collection process, as previously mentioned- rather than a single individual wearing the dosimeter for seven months, the dosimeters were rotated between work teams within a single occupation. In light of these considerations and given that the annual UVR dose was of relevance for the purposes of calculating the RR, it was possible to obtain this value through extrapolation. Furthermore, there were no missing values, and all the necessary values could be readily calculated based on the data provided by the MEAOW study. To provide a brief summary and clarification, while some of the data obtained through the MEAOW study was found to be incorrect, possibly due to the inappropriate use of dosimeters, and consequently excluded from analyses, this did not constitute an issue of "missing data" because, due to the duration of the study, enough data was collected to compensate for this exclusion, allied to the fact that the actual data for the RR calculation was calculated. Moreover, the data obtained from the MEAOW study was initially analysed on the basis of "half an hour" intervals with a view to determining which data should be included or excluded. Due to the scale of the data entry, it would have no impact on the overall seven-month period, should data have been excluded. Moreover, with regard to the number of days on which each dosimeter was worn, the researchers involved in the MEAOW study were meticulous in ensuring that daily exposures were not taken into account in the event that a dosimeter was worn for less than five hours per day, ensuring accurate daily readings. The data extraction and analysis were conducted with the utmost care and attention to detail.

Examples of data that were excluded could include instances where the data sets from certain participants or dosimeters yielded negative values, which is not possible as there is no negative exposure, only null exposure. Regarding the recreational UVR dose, since it was set at 297 SED (34, 44) and used as the base value, it was not, in any case, a possible missing value.

Based on the fact that there was no missing data regarding occupational and recreational UVR dose, there were no missing data for the RR calculation and no missing results.

Bias

It should be noted that, although the present paper employs secondary data, several potential biases must be considered when analysing the results. In regard to the model utilised for the calculation of RR, both model specification bias and omitted variable bias may have been introduced as a consequence of the fact that the statistical model employed for the calculation of RR was incorrectly specified. This was evidenced, for example, by the absence of a satisfactory explanation for the amplification factor being set at 2.5. Furthermore, there is a potential for bias due to the fact that the formula used in the model does not account for significant factors (such as genetic predisposition for SCC development, lifestyle, use of Personal Protective Equipment (PPE) or other environmental exposures that are considered risk factors for SCC). This may have resulted in an inaccurate estimation of risk, as the model did not fully explain the variation in SCC risk. The aforementioned factors may collectively have contributed to confounding bias, given that the model did not take into account variables that affect the outcome being assessed, namely RR associated with the development of SCC.

Additionally, the data from the MEAOW study may present selection bias, as the study population may not be representative of the general population. Furthermore, measurement bias may have arisen from inaccuracies in the quantification of exposure levels. This is not only due to the possibility of the dosimeters not being equally calibrated, but also because not all participants used the digital dosimeters for the same duration, which introduces a further potential source of error, as the inference of the cumulative UV dose received by each participant was necessary.

Furthermore, the above-mentioned issues with the dosimeters and their utilisation may have contributed to information bias, due to errors in data recording/ collection.

Given the constraints that might have arisen regarding the data set, which was previously collected, and the absence of an alternative SCC risk calculation/ estimation model, all the potential biases were considered during the analysis of the results. A more comprehensive examination of these potential biases can be found in the discussion section of this research, ensuring the validity and reliability of our findings regarding the RR of developing SCC.

Ethics

As this study makes use of data that has been previously collected, it is not anticipated that any significant ethical concerns will arise. Furthermore, it is essential to highlight that no personal data was employed in this study; only exposure data was utilised, which is not in any way associated to personal information and from which no personal information can be inferred. All the data derived from the MEAOW study was solely physical, specifically UV dose in J/m^2.

Regarding the study from which the data was derived (39), informed consent was obtained in accordance with the relevant ethical guidelines. The information sheet provided to all eligible participants in the study offered comprehensive details regarding the study's objective, the methodology employed for data collection, and the participants' rights to withdraw from the study at any point. It was of the utmost importance to ensure the confidentiality and security of the data in order to guarantee the well-being of the participants and to prevent any potential harm, and it still is. Moreover, as the study was developed by a partnership of institutions (including academia and the municipality (CML)), the Data Protection Officers from the aforementioned partners were consulted and a Partnership Agreement was signed.

Notwithstanding the absence of direct participant involvement for the purposes of this thesis and the absence of any personal data involvement, ethical considerations were taken into account. The utilisation of secondary data necessitated strict adherence to data protection and privacy legislation, ensuring that the data employed was fully anonymised. Furthermore, the study's design respects intellectual property rights and acknowledges all data sources, thereby ensuring the integrity of the research.

The development of this thesis was conducted in accordance with the principles of research integrity, and any instances of unethical conduct, such as data fabrication or plagiarism, were avoided.

Results

Study Participants and dosimeter data

The CML employs a workforce of 10,388 individuals across approximately 400 work institutions and activities, comprising a diverse range of over 65 occupational groups, both indoor and outdoor. From the 10th of April to the 31st of October 2023, UVR data was collected from individuals employed by the CML and engaged in outdoor work. A total of 91 outdoor workers from the CML participated in the MEAOW study, utilising 49 digital dosimeters for data collection. Hence, the data set for the present study was derived from the usage of 42 personal electronic dosimeters by 91 participants.

Over the course of the seven-month data collection period, the 91 outdoor workers rotated the digital dosimeters within their respective work teams. This rotation was implemented with the objective of ensuring maximum compliance during the data collection period of seven months and indicates that a single dosimeter was used by a number of outdoor workers engaged in the same occupational activities. This approach was also useful as it ensured the possibility of data collection during the summer, a period when workers typically take their annual leave- while one participant was absent on vacation, another one from the same occupation could use the dosimeter. In some teams, specifically the pavers, sailors, and one graveyard team, the same individual used the dosimeter for the entirety of the seven-month study period.

The following table presents the information regarding the work teams, along with the locations in which they operated during the seven-month data collection period.

Table 1 List of outdoor workers who contributed with data for the present study. Occupational team, number of team members and location of operation

Occupation (teams)	Number of workers	Location
Gardeners	18 (14+4)	Avenida de Ceuta and Campo Grande Garden
Sanitation Workers	25	Entire city
Asphalters	8	Entire city
Pavers	6	Entire city
Gravediggers	32 (19+8+5)	Alto de São João, Benfica and Prazeres
Sailors	2	Tagus River

It should be noted that during the MEAOW study, six gardeners withdrew from the study. However, the study collected data from the remaining 12 gardeners and the data collected until the moment of drop out was included- this was possible due to the establishment of work teams and the rotation of the dosimeters.

The data collected during the MEAOW study, specifically the erythemal UVR exposure dose, along with a comprehensive summary of the complete data entries, can be found in Table 6 of the appendix. In summary, Table 6 presents a synopsis of the data obtained from the MEAOW study, with 42 dosimeters recording a total of 3,355 days of valid data over a seven-month period. The total number of days recorded per occupation exhibited considerable variation, with gravediggers and pavers contributing the most to the study. It is noteworthy that the highest daily UV dose was recorded by an asphalter (1,833.43 J/m^2), despite pavers exhibiting the highest average UV exposure. In terms of UVR exposure by occupation, it was the sailors that presented the highest UVR dose. Additionally, it should be noted that only the pavers were not exposed to concentrations above the average limit. These variations are closely linked to the number of days each dosimeter was worn (bearing in mind that a single dosimeter was worn by more than one individual within the same occupation). It is noteworthy that seven dosimeters were excluded from the data set due to invalid readings, leaving data from 42 out of the 49 initially deployed. Further discussion on data validity and insights regarding exposure patterns can be found in the dissertation's discussion section.

As the model used for RR calculation was based solely on cumulative UV dose and employed a fixed age value, participants' sociodemographic characteristics were not factored into the analysis.

Average Annual UV Dose and Standard Erythemal Dose

Annual recreational UVR dose

A dose of 297 SED per year for the face was selected as a reference value for recreational exposure. As previously stated, this value was derived from the study conducted by Milon and colleagues (34), representing the recreational dose for office workers in Milan, a location surveyed by the Expolis study (43, 44).

Annual occupational and lunch hour UVR dose

In regard to the annual occupational UVR dose, the calculations carried out took into account two distinct scenarios. The initial scenario depicts the actual circumstances of outdoor workers in Lisbon, who typically engage in seven hours of work per day and allot one hour for lunch, which is also spent outdoors (eight hours in total, equivalent to a full working day). This is illustrated in Table 2. The veracity of this information is corroborated by the graph in Figure 4, which illustrates the times of day during which UV dose measurements were collected. If the workers consumed their lunch in an indoor setting, the dosimeter would all register a reading of 0 J/m², however, this did not occur, confirming they have their lunch generally outdoors. The second scenario is presented for the purpose of comparison and hypothesis testing, in order to demonstrate how and if an increase in the number of hours spent outdoors will result in an elevated risk of developing SCC. It was hypothesised that a greater number of hours spent outside would result in a higher cumulative UV dose and an increased RR of developing SCC. The data regarding this alternative scenario (of nine hours outdoors, during occupational activities and including one hour for lunch) may be found in the appendix in table 7. To calculate the average UVR dose experienced by an outdoor worker in an occupational context, it was assumed that the duration of a working year is approximately 239 days. This is based on the premise that workers in Portugal are entitled to 22 days of annual leave and that a year comprises 52 weekends, amounting to 104 days (calculated as 365 minus 104 plus 22).

In summary, Table 2 shows the UVR doses and yearly cumulative solar UV exposure in different outdoor occupations, revealing significant variability in UVR doses, with sailors, pavers, and gravediggers showing the highest cumulative exposures over a 239-day work year.

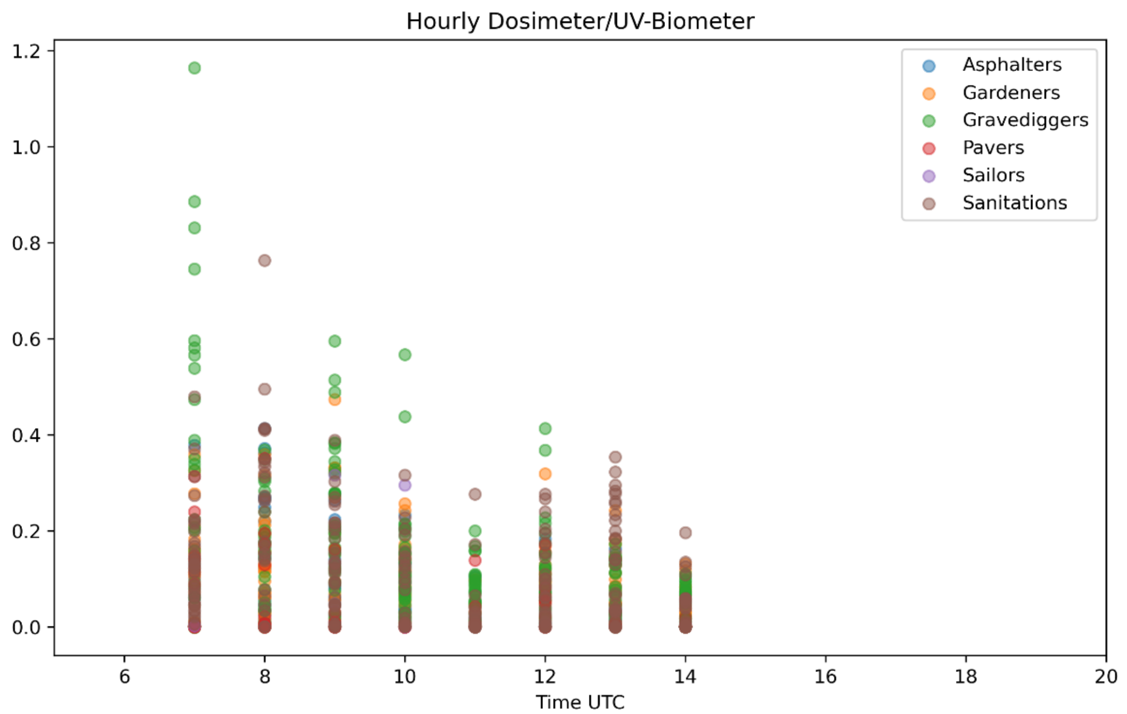

Figure 4 Hourly dosimeters to UV-Biometer dose ratios versus time for six occupational groups

Table 2 Annual Occupational UV Exposure Metrics for outdoor workers in Lisbon, considering they work 7 hours per day and have one hour for lunch (8 hours in total)

Occupation	Dosimeter	UVR dose (J/m2) per hour	UVR dose (J/m2) per working day (7+1h)	UVR dose (J/m2) per year (239 days)- Yearly cumulative UV dose	SED per year (239 days of work)
Gravedigger	PRT-2023-900-001	2.455	19.639	4693.638	46.936
Gravedigger	PRT-2023-900-002	0.396	3.169	757.449	7.574
Gravedigger	PRT-2023-900-003	0.347	2.776	663.374	6.634
Gravedigger	PRT-2023-900-004	0.253	2.021	483.081	4.831
Gravedigger	PRT-2023-900-005	0.517	4.133	987.770	9.878
Gravedigger	PRT-2023-900-006	0.331	2.644	631.981	6.320
Gravedigger	PRT-2023-900-007	0.533	4.261	1018.360	10.184
Gravedigger	PRT-2023-900-008	0.226	1.811	432.846	4.328
Gravedigger	PRT-2023-900-009	4.192	33.537	8015.263	80.153
Gravedigger	PRT-2023-900-010	0.366	2.925	699.017	6.990
Pavers	PRT-2023-900-011	0.028	0.221	52.756	0.528
Pavers	PRT-2023-900-014	0.060	0.480	114.646	1.146
Pavers	PRT-2023-900-016	0.008	0.065	15.494	0.155
Pavers	PRT-2023-900-018	0.021	0.171	40.771	0.408
Pavers	PRT-2023-900-019	8.726	69.805	16683.434	166.834
Gardener	PRT-2023-900-021	1.311	10.485	2505.982	25.060
Gardener	PRT-2023-900-022	2.500	19.998	4779.429	47.794
Gardener	PRT-2023-900-023	0.486	3.888	929.212	9.292
Gardener	PRT-2023-900-024	0.668	5.340	1276.349	12.763
Gardener	PRT-2023-900-025	1.332	10.652	2545.910	25.459
Gardener	PRT-2023-900-026	0.894	7.153	1709.451	17.095
Gardener	PRT-2023-900-027	0.745	5.961	1424.602	14.246

Gardener	PRT-2023-900-028	0.200	1.599	382.181	3.822
Gardener	PRT-2023-900-029	1.605	12.843	3069.421	30.694
Gardener	PRT-2023-900-030	0.472	3.777	902.594	9.026
Sanitation	PRT-2023-900-031	0.454	3.629	867.234	8.672
Sanitation	PRT-2023-900-032	0.199	1.589	379.811	3.798
Sanitation	PRT-2023-900-033	0.167	1.337	319.591	3.196
Sanitation	PRT-2023-900-034	0.234	1.869	446.758	4.468
Sanitation	PRT-2023-900-035	0.248	1.981	473.462	4.735
Sanitation	PRT-2023-900-036	0.254	2.030	485.079	4.851
Sanitation	PRT-2023-900-037	0.328	2.624	627.079	6.271
Sanitation	PRT-2023-900-038	0.362	2.900	693.040	6.930
Asphalters	PRT-2023-900-039	0.164	1.310	313.098	3.131
Asphalters	PRT-2023-900-040	0.063	0.507	121.125	1.211
Asphalters	PRT-2023-900-041	0.350	2.801	669.477	6.695
Asphalters	PRT-2023-900-042	0.520	4.156	993.306	9.933
Asphalters	PRT-2023-900-043	0.248	1.987	474.868	4.749
Asphalters	PRT-2023-900-044	1.450	11.600	2772.462	27.725
Asphalters	PRT-2023-900-045	0.107	0.856	204.469	2.045
Asphalters	PRT-2023-900-046	0.226	1.806	431.698	4.317
Sailor	PRT-2023-900-048	2.819	22.555	5390.690	53.907

Average Annual UVR Dose and SED by Occupation

The calculation of the annual UVR dose and the SED were also performed on an aggregated basis according to occupation. The results pertaining to the "real-world" scenario are presented below in Table 3. The results pertaining to the 9-hour scenario are presented in the appendix in Table 8.

Table 3 Yearly UV dose and SED, considering workers work a total of 8h per day

Occupation	UVR dose (J/m2) per year (239 days)- Yearly cumulative UV dose- considering 1 working day to be of 8h (7+1)	SED per year (239 days)
Gravedigger	1838.278	18.383
Paver	3381.420	33.814
Gardener	1952.513	19.525
Sanitation	536.507	5.365
Asphalters	747.563	7.476
Sailors	5390.690	53.907

Based on the Table 3, on average, those engaged in sailing are more exposed to solar UVR. Gravediggers and gardeners are in second place, showing quite similar results.

Cumulative UV Dose

Given that the annual recreational UVR dose is independent of age (34), it was reasonable to assume that the recreational dose would remain constant over the 60-year period for which the RR model is valid (34). Therefore, in terms of recreational UVR dose, a person would receive a total dose of 17,820 SED over a period of 60 years (297 x 60). Furthermore, it was established that the occupational UVR dose also remained constant throughout the 25-year period of employment (34). This is based on the premise that an individual is employed in the same occupation over the course of these 25 years and works seven hours per day plus one for lunch, spent outside. As a result, the cumulative occupational UVR dose (25 years) was calculated and is presented in Table 9 in the appendix. These values were used for the calculation of the RR (34). For details regarding the nine-hour work scenario, please refer to Table 10, also in the appendix.

Risk Calculation

Individual

Table 4 presents the RR values calculated using the model developed by Milon *et al.* (34) for the purpose of assessing the risk of outdoor workers developing SCC in comparison to indoor workers who take their lunch inside and, therefore, are only exposed to the sun in recreational settings.

Table 4 RR and increased risk (%) of developing SCC when exposed to solar UVR for a total of 8 hours per day in an occupational setting

Occupation	Dosimeter	Cumulative SED (25 years)- 8h of work per day	Relative Risk	Increased risk (%)
Gravedigger	PRT-2023-900-001	1173.409	1.173	17%
Gravedigger	PRT-2023-900-002	189.362	1.027	3%
Gravedigger	PRT-2023-900-003	165.843	1.023	2%
Gravedigger	PRT-2023-900-004	120.770	1.017	2%
Gravedigger	PRT-2023-900-005	246.943	1.035	4%
Gravedigger	PRT-2023-900-006	157.995	1.022	2%
Gravedigger	PRT-2023-900-007	254.590	1.036	4%
Gravedigger	PRT-2023-900-008	108.211	1.015	2%
Gravedigger	PRT-2023-900-009	2003.816	1.305	31%
Gravedigger	PRT-2023-900-010	174.754	1.025	2%
Pavers	PRT-2023-900-011	13.189	1.002	0.2%
Pavers	PRT-2023-900-014	28.662	1.004	0.4%
Pavers	PRT-2023-900-016	3.873	1.001	0.1%
Pavers	PRT-2023-900-018	10.193	1.001	0.1%
Pavers	PRT-2023-900-019	4170.858	1.692	69%
Gardener	PRT-2023-900-021	626.495	1.090	9%

Gardener	PRT-2023-900-022	1194.857	1.176	18%
Gardener	PRT-2023-900-023	232.303	1.033	3%
Gardener	PRT-2023-900-024	319.087	1.045	5%
Gardener	PRT-2023-900-025	636.477	1.092	9%
Gardener	PRT-2023-900-026	427.363	1.061	6%
Gardener	PRT-2023-900-027	356.151	1.051	5%
Gardener	PRT-2023-900-028	95.545	1.013	1%
Gardener	PRT-2023-900-029	767.355	1.111	11%
Gardener	PRT-2023-900-030	225.649	1.032	3%
Sanitation	PRT-2023-900-031	216.808	1.031	3%
Sanitation	PRT-2023-900-032	94.953	1.013	1%
Sanitation	PRT-2023-900-033	79.898	1.011	1%
Sanitation	PRT-2023-900-034	111.690	1.016	2%
Sanitation	PRT-2023-900-035	118.366	1.017	2%
Sanitation	PRT-2023-900-036	121.270	1.017	2%
Sanitation	PRT-2023-900-037	156.770	1.022	2%
Sanitation	PRT-2023-900-038	173.260	1.024	2%
Asphalters	PRT-2023-900-039	78.275	1.011	1%
Asphalters	PRT-2023-900-040	30.281	1.004	0.4%
Asphalters	PRT-2023-900-041	167.369	1.024	2%
Asphalters	PRT-2023-900-042	248.326	1.035	4%
Asphalters	PRT-2023-900-043	118.717	1.017	2%
Asphalters	PRT-2023-900-044	693.115	1.100	10%
Asphalters	PRT-2023-900-045	51.117	1.007	1%

Asphalter	PRT-2023-900-046	107.924	1.015	2%
Sailor	PRT-2023-900-048	1347.673	1.200	20%

The RR values presented in the table range from 1.001 to 1.692. The highest RR of 1.692, observed for a cumulative SED of 4170.86, indicates a 69% increased risk of developing SCC compared to the baseline. This table demonstrates that individuals with higher cumulative UV exposure levels are at a significantly greater risk of developing SCC. The data presented in the table consistently demonstrates that an increase in cumulative SED is associated with a corresponding rise in the risk of developing SCC, particularly at higher exposure levels. This reinforces the established relationship between prolonged UV exposure and the elevated risk of skin cancer among individuals engaged in outdoor occupations.

The lowest RR of 1.001 indicates a minimal or negligible additional risk for very low exposure levels, which correlates with lower cumulative SEDs.

The results of the analysis pertaining to the cohort of outdoor workers engaged in their occupations for a period of nine hours are presented in Table 11, in the appendix.

The results presented in Table 11 in the appendix are consistent with those presented in the preceding table. The highest value of RR is 1.794, corresponding to a cumulative SED of 4692.216 J/m² over a 25-year period. This value indicates a 79.4% increase in the risk of developing SCC in an individual exposed to solar UVR during an eight-hour work shift, when compared to someone primarily exposed to UVR in recreational settings.

The data presented in both tables clearly demonstrate that there is a direct correlation between the risk of developing SCC and higher cumulative UVR exposure. This risk is amplified when exposure levels are more elevated, as evidenced by a comparison of the data within each table or a comparison between the tables themselves.

By occupation

Furthermore, the RR of developing SCC was calculated according to occupational group. The results are presented in the Table 5. The values pertaining to the nine-hour shifts are presented solely for the purpose of comparison and to demonstrate that an increase in UVR exposure correlates with an elevated risk of developing SCC.

Table 4 RR of developing SCC by occupation

Occupation	Average Cumulative SED (25 years)- 8h shift	RR (8h)	Average Cumulative SED (25 years)- 9h shift	RR (9h)
Gravedigger	459.569	1.066	517.016	1.074
Paver	845.355	1.123	951.024	1.139
Gardener	488.128	1.070	549.144	1.079
Sanitation	134.127	1.019	150.893	1.021
Asphalters	186.891	1.026	210.252	1.030
Sailors	1347.673	1.200	1516.132	1.226

A transition from an eight-hour to a nine-hour workday has been observed to result in a slight increase in cumulative SED and RR across all occupational categories, indicating a subtle but consistent elevation in the risk of developing SCC. Among the various occupational groups, sailors seem to be exposed to the highest cumulative SED and, consequently, have the greatest RR values, indicating a higher risk of SCC. In contrast, the lowest cumulative SED and RR values were observed in municipality sanitation workers, indicating a comparatively lower risk of developing skin cancer in their profession.

A comparative analysis of occupational results (Table 5) versus individual dosimeter readings (Tables 4 and 11) reveals significant discrepancies. For instance, Table 5 indicates that sailors have the highest cumulative SED and RR, which suggests a significantly elevated risk of SCC. Conversely, Table 4 indicates that pavers have the highest RR. This indicates a considerable degree of variability in individual exposure levels within occupational groups, thereby demonstrating that even within the same profession, exposure can vary considerably.

By percentage of exposed body (individual)

The study by Milon et al. (34) estimated that only about 0.124 m² of the body is exposed to UVR during outdoor work, representing a mere 0.6% of the body's total surface area of approximately 2 m². While the RR of developing SCC is typically calculated based on UVR dose (J/m²), or SEDs, we also calculated the RR using the percentage of body area exposed, to compare results and assess whether this influenced the findings. This information may be found in Table 12. Despite the limited exposed area, Table 12 indicates that outdoor workers still exhibited a higher risk of developing SCC in comparison to indoor workers, emphasizing the significance of even minimal sun exposure.

Discussion

In the field of epidemiological occupational health and clinical research, the interpretation of statistical models is of utmost importance, as it enables the translation of data into actionable insights.

In the present research, the RR of outdoor workers developing SCC was calculated, and a positive correlation between the cumulative solar UVR exposure and the RR of developing SCC was found.

A closer examination of the individual results reveals a strong correlation between the measured UVR exposure levels of outdoor workers and the predicted risk of SCC. Those with higher cumulative UVR exposure over a 25-year period exhibited a significantly elevated RR for developing SCC. For instance, the highest RR (1.692) corresponded to the highest cumulative UV dose of 4170.86 SED over a 25-year period in occupational settings. Conversely, the lowest RR value (1.001) was associated with a cumulative UV dose of 3.873 SED over the same period, representing the lowest value.

It is noteworthy that both the RR values mentioned above (corresponding to the highest and lowest values) pertain to individuals engaged in the same professional activity, namely paving. Notwithstanding, a notable discrepancy was observed in their UV exposure levels. This raises the question of whether the digital dosimeter used by the individual with the lowest UV dose may have produced inaccurate readings, or whether the number of days the dosimeter was worn may have been a contributing factor. It is also important to note that the knowledge, attitudes, and practices of those who used the dosimeters may also have affected the data collection. Some individuals are more compliant with health promotion and disease protection campaigns, for example, and lower UVR doses could be associated with the use of PPE- which would be quite positive if it indeed were the case. It is also noteworthy that at CML, some occupation managers have the autonomy to select the specific area they wish to work at, including for this particular occupation. During the data collection process, it seems that these managers did in fact consistently opt to/ attempted to work in shaded areas. Such a scenario may have arisen, for instance, in the event that an avenue required paving. In such cases, the managers would typically opt to commence work on the side of the avenue that afforded shade in the morning, and then proceed to the other side in the afternoon, where shade would be available at that time.

A review of the data as a whole indicates a general trend whereby an increased cumulative exposure to UVR is associated with an elevated risk of developing SCC. This underscores the potential contribution of cumulative UVR dose as a risk factor for SCC.

The analysis reveals that, although some RR values are recorded as very closer to 1, indicating no apparent or almost negligible increase in risk. It is, however, important to note that no RR value was actually 1. A more detailed examination of the data and the calculation of the percentage increase in SCC risk demonstrates that there is, in fact, no dosimeter reading that shows a 0% risk increase. This indicates that, in each case, the risk of developing SCC is increased as a result of exposure to UVR in outdoor occupational settings.

The observed, lower than expected RR values just mentioned (close to 1) may be indicative of a rather interesting hypothesis: in the context of occupational health, it is crucial to acknowledge that outdoor workers may, in fact, be less exposed to specific occupational hazards than their indoor counterparts. This seemingly paradoxical situation can be attributed to the heightened awareness and subsequent behaviours adopted by those engaged in outdoor professions. The regular awareness of the potential dangers of their environment may encourage outdoor workers to utilise PPE and sunscreen, thereby reducing the risks associated with prolonged exposure to, in this case, UVR. Consequently, this active approach to safety may contribute to lower-than-anticipated RR values when comparing outdoor and indoor occupational exposure to solar UVR. Such findings highlight the necessity for a nuanced understanding of exposure levels and the effectiveness of protective measures in different work settings.

To enhance the interpretation of the data, Table 14 developed, providing a comprehensive overview of the number of days on which each dosimeter captured valid readings, along with an estimate adjusted to account for full 8-hour shifts, with the intention of enhancing the interpretation of the data. This detailed approach enabled a more accurate comprehension of the extent of UV exposure during working hours. In the MEAOW study, dosimeters were deployed among outdoor occupational groups over a seven-month period, and the data was extrapolated to reflect an annual UV dose based on the assumption of a 239-working-day year, as outlined in the methodology.

Although no dosimeter was worn continuously for the entire seven-month study period (which would amount to approximately 140 working days), the distribution of data successfully captured the most critical months—spring through autumn—when UV exposure is typically highest due to more favourable atmospheric conditions and reduced cloud cover. This seasonal focus is advantageous in that it ensures the study accurately reflects the periods of maximum UV exposure, thereby providing robust insights into occupational UVR risk.

In the MEAOW study, days with at least five hours of valid data collection were included in the overall analysis. Although this specific information was not accessible for the purposes of this dissertation, Table 14 offers a meaningful comparison between the actual number of days the dosimeters were worn and an estimated equivalent for eight-hour shifts, thereby facilitating a more accurate interpretation of the data.

Another noteworthy finding is that, out of the 42 valid entries, 11 dosimeters were worn for less than a month. Although it might be anticipated that shorter wear durations would be associated with lower RR values, a notable and significant finding is that the highest RR was recorded by a dosimeter worn for only four days by pavers. This illustrates that even brief periods of elevated exposure can result in markedly elevated risks, emphasising the necessity of UV protection irrespective of exposure duration. Despite the positive aspects just presented, it is crucial to acknowledge the possibility of inconsistencies in dosimeter usage among participants. It is possible that the dosimeters were used intermittently or for shorter periods than a full workday. Anticipating this issue, the MEAOW study researchers distributed a smaller number of dosimeters than the number of workers in each occupational team (hence why there were 91 individuals and only 49 dosimeters). This strategy ensured that dosimeters could be shared among workers on different days, thereby optimising the time for which they could be used. Therefore, dosimeters recording fewer days may be indicative of less frequent use within a team, whereas those with more days suggest more consistent use. A comparison of the results by occupational category (Table 5) with the overall results captured by each dosimeter (Tables 4 and 11) indicates that the increase in the RR of developing SCC is less pronounced. The highest average cumulative UV dose by occupational group was observed among sailors, who also exhibited the highest RR of developing SCC. In particular, sailors are found to have a 20% and a 22.6% increased risk of developing SCC when engaged in eight-hour shifts and nine-hour shifts, respectively, over the course of 25 years, in comparison to individuals engaged in indoor work during the same time frame.

The relatively low RR values observed across occupational groups, in comparison to the full data set, may be attributed to significant inter-individual variability in UVR dose readings, which resulted in lower mean values. Some workers were exposed to considerably high levels of UV radiation, while others had notably low exposure, all within the same occupational group. Such variability may result in lower average RR values for each occupation when compared to the individual results for each occupation.

The discrepancies in RR values among occupations may be attributed to a multitude of factors, particularly the variability in work locations. For instance, some occupations may have more or less access to shaded areas, which could influence the overall exposure to UV radiation.

Nevertheless, the mean RR values for gravediggers and gardeners were observed to be higher than those for sanitation workers and asphalters. Specifically, the mean RR values for gravediggers and gardeners were 1.066 and 1.070 (8-hour shift), respectively, compared to lower values for sanitation workers (1.019) and asphalters (1.026). These findings indicate that despite the potential for more shaded work environments, the higher RR values observed in gravediggers and gardeners highlight the complex interplay between UV exposure and occupational settings. Further analysis of the specific conditions in cemeteries and gardens, where gravediggers and gardeners are employed, could provide additional insights, and is recommended for future studies.

In the case of the sanitation workers and asphalters, the lower than anticipated RR values may be attributed to the utilisation of PPE, inaccurate dosimeter readings or data logging, or even the specific location in which these individuals are employed. To illustrate, sanitation workers may spend a considerable portion of their workday inside their vehicles, which would result in a reduced UVR dose due to the enhanced level of protection afforded to them by the vehicle itself. Similarly, asphalters are likely to benefit from the use of protective clothing and equipment, including long-sleeved shirts, long trousers, and face masks, which may be worn even during the summer months. This is not because of exposure to the sun, but to avoid exposure to asphalt itself. In some instances, supplementary protective headgear may also be utilised, thereby further enhancing sun protection, albeit in an indirect manner. With regard to sailors, it is essential to note that their work shifts in outdoor environments are distinct from those of other occupations included in the study in the context of the CML. Although sailing is not typically regarded as a seasonal occupation in Lisbon, these workers typically engage in sailing activities exclusively during the summer months (June to September). Furthermore, the nature of their work entails that they only sail if there is a booked trip, which means that no eight-hour shift is generally entirely spent on a boat. Even when on the vessel, sailors are not required to be outside; they may spend their time in the shade. When not engaged in sailing activities, this occupational group typically spends their time indoors, performing different activities on computers, and such. Despite the considerations just outlined, it is notable that the highest RR value was recorded for sailors, despite the fact that the overall average RR by dosimeter for individuals in this group was lower than that observed for other individuals in other groups. This suggests that the elevated RR values observed in sailors are worthy of note, given their intermittent exposure and the fact that they do not typically spend a full work shift outside. The distinctive work environment and schedule of sailors highlight the necessity of considering these factors when interpreting UV exposure and associated risk levels, as well as the need for the correct implementation of occupational policies regarding solar UVR, given that even in lower exposure time frames, the RR remains high.

Additionally, and despite the information just presented, the precise degree of solar exposure for any given individual or cohort is subject to variation due to the specific location and duration of their outdoor activity.

It is important to note that, despite the observed increase in risk being lower than anticipated (in terms of interpretation by occupational groups), all outdoor occupations included in the study were associated with an elevated risk of developing SCC.

In light of the presented information, it is imperative to highlight that in all instances, the increase in cumulative UVR exposure in occupational settings was linked to an elevated risk of developing SCC.

Generalization of results to the entire country

In extrapolating the results to the wider Lisbon region, it is important to consider that not all individuals engaged in the outdoor activities included in the study have the same working shifts. For example, while this is not the case in all councils of Lisbon, sanitation workers in some councils are typically engaged in nighttime work, with minimal exposure to sunlight during their shift. Hence, to ensure the accuracy of extrapolating the RR values to the rest of the Lisbon district, it would be prudent to replicate the methodology employed in the MEAOW study with a larger and more geographically dispersed cohort of outdoor workers in Lisbon.

With regard to geographical variations, it is essential to consider how the calculated RR for developing SCC in specific areas of the Lisbon region can be extrapolated to the rest of the country (Portugal). In Portugal, the topography and altitude exert a considerable influence on the levels of UVR experienced. Regarding the altitude, as it rises, the levels of UVR increases (45). Therefore, regions situated at higher altitudes will experience higher levels of UVR than regions situated at lower altitudes. Furthermore, and due to Portugal's diverse topography, there is considerable variation in UVR exposure, due to the fact that this country is composed of both coastal lowlands, and also mountainous regions (mainly in the interior of the country) (45).

In comparison to the southern regions of Portugal, particularly the Algarve- renowned for its sunny climate (and higher UVR levels), the northern regions exhibit lower levels of UVR. This is attributed to the greater distance from the equator and the prevalence of cloud cover, which reduces UV exposure (46, 47). The central region of Portugal can experience moderate levels of UVR. However, in the areas situated at higher altitudes UVR levels are elevated (48). The eastern region, particularly around Portalegre, is characterised by a Mediterranean climate with continental influences, which could be expected to result in higher UVR levels, especially during the summer months when the UV index averages around 7-8 (46, 49, 50). The Portuguese islands, such as Madeira and the Azores, are situated in a geographical position that allows for varying UVR levels (51). However, they typically experience higher UVR levels than mainland Portugal due to their closer proximity to the equator and the often-clearer skies, which allow more UV radiation to reach the surface (46, 49).

Based on all mentioned, the RR values calculated for Lisbon may be used to develop protective measures for the rest of the country. Despite slight climate differences between regions, Portugal, with its Mediterranean climate and geographical position, experiences significant levels of UVR. This probably translates, across the entire country, to high UV dose, and consequently, high cumulative UV dose and RR of developing SCC in occupational settings.

It is also important to consider that, in comparison to Lisbon, despite there being cities/regions with similar characteristics to the latter, such as Porto and Braga, other regions have more outdoor occupations and at-risk groups, not only due to geographical regions, but also socioeconomic differences. For instance, in more rural areas such as the Alentejo and the Douro Valley, agriculture represents a significant source of employment, with workers frequently exposed to prolonged periods of sunlight. Furthermore, in coastal regions such as the Algarve and parts of the Azores, sailing and fishing are significant industries, thereby increasing the likelihood of prolonged outdoor exposure and the associated risks. It is essential to consider these factors. It would be advisable once more to replicate the methodology employed in the MEAOW study with a larger and more geographically dispersed cohort of outdoor workers throughout Portugal.

The information regarding the differing UVR levels between geographical areas allows us to introduce the concept of a geographical area that may have influenced the RR calculation. This is because the recreational SED value used was derived from the study by Milon *et al.*, in which this value was derived from indoor workers in the city of Milan, Italy. This may be considered a limitation of the results.

While numerous factors influence the level of UVR experienced on Earth, focusing on altitude, latitude, and proximity to the equator allows us to conclude that, in general, Lisbon may receive a higher UVR dose. This is due to the fact that Lisbon is situated at a more southerly latitude (38° N) (52) than Milan (45° N) (53). The proximity to the equator results in a more intense and direct angle of sunlight, consequently increasing the exposure to UVR throughout the entire year. Furthermore, although both cities are situated at a similar elevation, Milan is located slightly inland, surrounded by hilly terrain (54, 55). This could potentially result in a reduction in UVR exposure compared to the coastal location of Lisbon. Therefore, the accurate recreational UVR dose used for the RR calculation may be higher than the dose used in this study, which would result in higher RR values (meaning that the results possibly present an underestimation of the RR of SCC development). However, it is essential to consider that other factors, such as atmospheric conditions, may influence the level of UVR experienced in Lisbon, potentially leading to a reduction in the observed levels compared to Milan. To achieve a more precise comparison, it would be necessary to incorporate UV index forecasts or historical data that account for the specific conditions of each city. Additionally, the lack of data on environmental factors (e.g. cloud cover) may have resulted in inaccuracies in the measurement of UV exposure.

Limitations

In terms of the study's limitations, they serve to identify areas for improvement, while simultaneously providing valuable insights. The limitations of this research were all taken into account and seem to not be directly part of this thesis, but imposed on the study itself, due to the use of secondary data for the RR calculation.

In short, methodological discrepancies were identified in the usage and collection of dosimeter data, which may have influenced the study's outcomes. Furthermore, the partial monitoring of work shifts due to participant non-adherence may have resulted in imprecise assessments of UV risk. Notwithstanding these limitations, the study offers valuable insights into UV exposure trends and provides a robust foundation for further research in diverse settings and conditions, with potential for methodological enhancement. It is possible that enhancing the sample size could have resulted in a greater degree of precision in the results and a broader applicability to the Portuguese population. Advancing to the Milon formula (34), it is essential to acknowledge its inherent limitations. These limitations are not exclusive to the formula employed here, but also extend to the other models from which it was derived.

To the best of our knowledge, no fully comprehensive models exist for estimating the risk of SCC, with the exception of the model initially proposed by Schothorst *et al.* (35), and by Slaper *et al.* (36) and subsequently developed by Milon *et al.* (34), in which the risk of SCC was estimated based on a subject's age and the total amount of UV exposure received during occupational activities, lunch breaks, and leisure time (34-36).

Analysing firstly the study by Schothorst *et al.* (35), it investigated the increased risk of skin cancer in patients with psoriasis undergoing long-term UVB phototherapy. By comparing the cumulative UVB doses in these patients with those typically received by healthy individuals from sunlight, a dose-response model suggested that the incidence of non-melanoma skin cancer (NMSC) could be 2.5 to 7.5 times higher in psoriatic patients than in outdoor workers. However, further analysis is limited due to restricted access to the full study data set (35).

Slaper et al (36) examined the effects of global ozone depletion, noting an increase in harmful solar UVR and a corresponding increase in skin cancer cases. They compared three scenarios - no restrictions (NR), the Montreal Protocol (MP) and the Copenhagen Amendments (CA) - and predicted additional annual skin cancer cases in the USA by 2100: 1.5 million (NR), 440,000 (MP), and 8,000 (CA); for Europe, the figures were 550,000 (NR), 170,000 (MP), and 4,000 (CA). The incidence of squamous cell carcinoma (SCC) appeared to be directly proportional to cumulative UV dose, with age and lifetime exposure being key factors (36). This led to two further studies: one on albino mice and another on long-term NMSC risks associated with UVB therapy (56, 57).

De Gruijl et al (56) conducted a controlled experiment on hairless albino mice exposed daily to UVR and followed the development of skin tumours. The study identified relationships between UV dose and tumour prevalence (P) and yield (Y), with a probability model showing how UV exposure accelerates tumour development. The study emphasised that SCC was strongly associated with UVR, while basal cell carcinoma (BCC) had a weaker association. The second study (57) presented a dose-response model for NMSC risk from UVB therapy, which highlighted the potential benefits of sun protection in reducing skin cancer risk. However, the predictions of the model exceeded the observed rates in Sweden (57). Both studies provided valuable insights, but lack of access to the full articles limited further analysis.

While the articles and models mentioned above provided a basis for estimating the risk of SCC, several issues require further investigation. In general, the approach of Schothorst *et al.* (35) and Slaper *et al.* (36) is an oversimplification of the complex biological mechanisms underlying carcinogenesis, as it assumes a linear relationship between age and UV exposure. Moreover, there is considerable variance in the values employed in the models, with no evident rationale for this. For instance, the values of the amplification differ between studies, despite all studies referencing one another and no rationale provided for this inconsistency. It is possible that further issues may emerge if access is granted to the studies that are currently unavailable.

In light of the above considerations, it is apparent that the model developed by Milon *et al.* (34) may be subject to certain limitations when employed to estimate the RR of SCC, given that it was developed on the basis of existing information, and that it is based studies engulfed in inconsistencies and doubts.

It appears that Milon *et al.* (34) did not take into account a number of crucial confounding variables and introduced an uncertain biological amplification factor, which may have introduced a degree of uncertainty into their model. Furthermore, the assumption that UV exposure affects individuals uniformly may not account for inherent differences in susceptibility, such as genetic predisposition or issues related to weakened immune systems. Moreover, relying exclusively on RR does not facilitate a comprehensive understanding of absolute risk.

Practical challenges emerge from data constraints in quantifying diverse UV exposures. In particular, the model developed by Milon *et al.* (34) gives rise to concerns regarding its generalisability, especially due to the data-driven limitations resulting from the inclusion of a limited number of variables within the formula, the assumptions of variable independence, and the challenges associated with risk factor dynamics. Additionally, the model does not account for changes in risk factors or changes in exposure patterns over time, nor does it consider the dynamic nature of SCC development. Moreover, the formula is only applicable for illustrating the RR at age 60, after 25 years of outdoor work, with the biological amplification factor set at 2.5 (34).

In the context of the identified limitations of current SCC risk estimation formulas, it is evident that there is a pressing need for their improvement in order to effectively address the rising incidence of skin cancer. These limitations, which include oversimplification, the neglect of key variables, and uncertainty in introduced factors, underscore the necessity for ongoing refinement. To enhance the precision and applicability of models in predicting SCC risk, it is essential to address these issues.

In addition to the limitations mentioned above, it is important to consider and keep in mind the potential biases that may be inherent in the data and the model used throughout the study. These have been identified in the methodology section and include model specification bias, omitted variable bias, selection bias and measurement bias. With regard to the model specification and the omitted variable bias, these were the result of inherent limitations in the RR model itself. To ensure that the lowest possible extent to which these biases influenced the results, the model was not altered, despite the identified limitations. This entailed maintaining the amplification factor and the recreational SED used in the original formula. Furthermore, no additional variables were incorporated into the model, despite their potential utility in accurately calculating the RR. It is believed that these will keep the power of the formula presented by Milon. Regarding selection bias and measurement bias, these were inherent to the source of data (MEAOW study (39)) and could not be addressed or minimised. Nevertheless, the potential influence of these biases was taken into account during the analysis and discussion of the results. However, it is important to note that these biases may still have an impact on the accuracy and generalisability of the findings regarding SCC risk.

Notwithstanding the issues mentioned, it is imperative to acknowledge that none of the observations indicate that the results could have been overestimated. In fact, the opposite was observed. The evidence indicates that all outdoor workers are at an elevated risk of developing SCC in comparison to indoor workers, who are only exposed to UVR in recreational settings.

Strengths

Despite the aforementioned issues and the observed increase in the RR of developing skin cancer, there has been a notable absence of studies attempting to address this problem.

In the context of modern research, the methodology employed in this thesis is distinctive in comparison to other studies in the field, as it addresses a notable gap in existing research. A comprehensive review of the literature reveals that, apart from the study by Milon *et al.* (34), which is the source of the RR model employed here, no other research has used such RR formula in their analysis. It is worth noting that Milon *et al.* relied on estimated UV doses, whereas the present study employs actual UV dose measurements, thus aligning with the recommendations for future research posited by Milon *et al.* themselves. Moreover, while several studies (14, to be exact) have cited Milon's work, they have predominantly referenced the empirical data without applying the RR formula (58-61). In regard to other studies that attempt to calculate the risk of developing SCC, there is considerable variation between studies. They generally do not employ a RR model like the one employed in this case. Alternatively, they attempt to calculate the risk of developing SCC through systematic reviews and estimations, or qualitative studies (62, 63). There is no application of a formula or model per se. The limited number of studies that do employ formulas frequently fail to address the risk in occupational settings. Furthermore, they often apply such formulas to cancer types that are not pertinent to this case (64), or to an excessively broad range of cancer groups (65). In addition, they frequently apply formulas in articles with a study objective that is too comprehensive, thus diluting the specificity required for a rigorous risk assessment (66).

A particular study (67) calculates the risk of developing SCC (among other things), employing univariate and multivariate logistic regression analyses. However, the study in question collected data on UVR exposure and dose through the use of questionnaires, which may have been subject to a number of issues, including recall bias and over- or under-estimation during the reporting phase (67).

The use of empirical data on UVR doses, coupled with the absence of similar studies, represents a significant strength of this paper. Given the health risks associated with UVR in occupational settings and the need to enhance understanding of its determinants to improve UV protection, the calculation of the RR of SCC development based on exposure data from diverse outdoor occupational groups was of paramount importance and significance.

Another strength was the fact that the majority of studies on occupational UV exposure, despite not belonging to the same study type, focused on specific occupations, with each study examining a single occupation. The data employed in this study comprises on-site evaluations conducted with the use of dosimeters by professionals engaged in a range of occupations. Thus, a comprehensive evaluation of UV exposure in various populations, including farmers, sailors, pavers, asphalters, and gardeners, has already been conducted. Furthermore, the data on UV exposure was collected through the use of dosimeters, which, despite the potential for certain limitations, still yield more accurate results than estimates of UV exposure or self-reported data.

Another strength that is worth keeping in mind is the fact that the study encompasses UVR doses from a substantial proportion of the year, thereby capturing pivotal periods of elevated exposure, and its comprehensive analysis enhances the precision of the findings.

Considering the aforementioned findings and their implications for risk estimation of SCC, it can be stated that the study makes a significant contribution to the existing body of knowledge in the field of public and occupational health epidemiology and to inform the development and introduction of enhanced public health and occupational health policies. Despite certain limitations, the study's findings are of value in informing the implementation of UVR protection measures and the development of occupational health practices, with potential benefits extending across Portugal. However, further studies are still required to enhance our understanding of this disease and its development in an occupational setting in terms of accuracy.

Conclusion

In conclusion, the evidence suggests that exposure to solar UVR increases the risk of developing SCC among outdoor workers, with RR values ranging from 1.026 to 1.200 in terms of occupational groups. However, when analysing the broader data set available, the risk of developing SCC was increased by about 69%Despite these findings, further investigation is still required.

The results of this study make a significant contribution to epidemiology, public health, occupational health, and clinical research. They highlight the importance of refining current risk assessment methods to drive improvements in public health policy and practice. In addition, these results have the potential to inform the design and implementation of better workplace protection measures against solar UVR. By identifying key determinants of exposure, the study lays the groundwork for more effective risk analysis and prevention strategies to protect outdoor workers from harmful UV exposure and its associated health risks.

Recommendations and Implications for Public Health and Occupational Safety

Recommendations for Outdoor Workers

The results of the study, although not without certain limitations, clearly demonstrated that occupational exposure to UVR exposure significantly increases the risk of developing SCC among those engaged in outdoor work. In light of these findings, a number of practical recommendations are put forth with the aim of mitigating the risk of developing NMSC. It is of the utmost importance to promote the use of UV-protective clothing, hats, and broad-spectrum sunscreen among those engaged in outdoor work. It is recommended that these items be made readily available and that their use be strongly encouraged or even mandated in all outdoor work settings. It is imperative that UV-blocking measures, such as the provision of shaded work areas, are implemented, particularly during periods of peak UV intensity. The utilisation of portable canopies or shelters has been demonstrated to be an efficacious method for the reduction of direct UV exposure. Modifying work schedules to circumvent periods of peak UVR, which typically occur during midday, can markedly diminish UV exposure. It is recommended that shifts be scheduled in the early morning or late afternoon to minimise risk.

The feasibility of these recommendations is contingent upon the specific occupational setting and region in question. In agricultural regions, where outdoor work is prevalent, the adoption of protective clothing and altered work schedules is a viable option, though it may necessitate educational initiatives and cultural adaptations, given that sun exposure is often perceived as less harmful. In coastal areas, where fishing and tourism-related activities are predominant, the implementation of shaded areas and the promotion of sunscreen usage are practical and realist measures that can be adopted. However, enforcement may prove challenging due to the mobile nature of the work. In larger urban areas such as Lisbon and Porto, the implementation of structured breaks and shaded areas may be more straightforward, although smaller municipalities may encounter difficulties due to resource constraints.

In order to provide support for these efforts, national health promotion campaigns should be launched with the objective of raising awareness about the risks associated with UV exposure. Furthermore, legislation should be introduced with the intention of enforcing mandatory breaks, the use of protective clothing, and sunscreen, particularly for vulnerable groups such as outdoor workers. It will be of significant importance to tailor these measures to specific regions and occupations across Portugal in order to enhance compliance and effectively reduce NMSC incidence (particularly SCC incidence).

Policy Implications

The prevalence of occupational injury and disease represents a significant burden on social security and healthcare systems globally, which in turn impedes the pace of economic development. Recent decades have seen a growing body of evidence indicating that exposure to UVR at work and during leisure time represents a significant risk factor for the development of NMSC. Nevertheless, despite heightened awareness since the 1980s and the introduction of numerous EU regulations addressing UVR risks, including initiatives by the World Health Organization (WHO) such as the UV Index, many UVR protective measures remain inadequately implemented, particularly in Portugal (39, 68). Despite the promotion of UV protection by the EU and WHO, current policies lack comprehensive guidelines (69, 70). Furthermore, there is a lack of adherence to these guidelines among outdoor workers and the general population (71), who appear to disregard the risks associated with solar UVR exposure. This may be attributed to a dearth of autonomy in declining work assignments, aesthetic considerations (given that tanned skin is a beauty standard in numerous Mediterranean countries, including Portugal), and the perception that the risks are not as substantial as they are purported to be (72).

In order to enhance the protection of outdoor workers from the risks associated with UVR, it is essential that a comprehensive policy review and overhaul be undertaken. It is recommended that governments implement regulations requiring employers to provide their employees with appropriate UV protective measures, such as broad-brimmed hats, long-sleeved garments, sunglasses, sunscreen, and shaded areas during peak UV intervals. The monitoring of compliance could be the responsibility of occupational health authorities. The construction of both fixed and portable shade structures in work zones with high solar exposure is of paramount importance for the consistent safeguarding of workers from UVR. Modifying work schedules to avoid peak UV times and incorporating UV protection measures into national health and safety regulations can enhance worker safety, becoming a standard component of workplace evaluations. Another potential strategy for enhancing the protection of outdoor workers from UVR risks is to incentivise employers through tax incentives or subsidies to invest in UV-blocking apparel or equipment. The ability of mid-level managers to organise the schedules and tasks of outdoor workers may also represent a significant organisational point, given their understanding of the demands of the job and their capacity to identify intrinsic factors that require consideration. In addition to solar UVR exposure, workers may also experience thermal discomfort during the UV peak hours.

The provision of shade in urban areas, as identified through satellite imagery, reveals significant discrepancies in the availability of shaded areas across different job sectors. It is of the utmost importance to address these disparities. The formulation of policy and design should be informed by questions such as how urban planners and employers can enhance outdoor workspaces to ensure sufficient shade and reduce UV exposure.

National or regional educational campaigns are of paramount importance in raising awareness among those engaged in outdoor work about the risks associated with UV radiation, and in particular the necessity for skin care and regular health checks. A UV index alert system, integrated with meteorological forecasts, could serve as a preventive tool, notifying workers and employers of days with elevated UV levels and the necessity for enhanced protective measures.

Those engaged in occupations that entail frequent exposure to UVR, including gardeners, sailors, farmers, construction workers and fishermen, and others, should be entitled to priority access to systematic skin cancer screenings and preventive strategies. It is of the utmost importance that these screening protocols be established through a collaborative approach involving dermatologists and public health entities to facilitate the prompt identification and management of skin cancer. The implementation of such proactive health measures has the potential to significantly reduce the prevalence of UV-induced skin cancers within these high-risk professions, thereby enhancing the collective well-being and safety of the workforce. It is worth noting that the CML offers this screening on a regular basis through its Occupational Medicine service.

Implications for Employers and Workers

It is of paramount importance that employers take action to mitigate the risk of UV exposure in the workplace. To implement effective preventive measures and foster a culture that prioritises UV protection, it is incumbent upon employers to develop clear UV protection policies and to identify ways of incentivising their employees to comply with them. Many possible policies were mentioned above. It is imperative that such policies, once developed and implemented, should be clearly communicated to all employees, with the emphasis placed on UV protection as a priority, rather than as an optional extra. It is the responsibility of employers to ensure that UV-protective equipment is readily available and accessible to all workers. Furthermore, the establishment of shaded areas for rest periods and the promotion of the utilisation of portable shelters can markedly diminish UV exposure during periods of peak intensity.

Modifying work schedules to avoid the period of peak UV radiation, which typically occurs between 10 a.m. and 4 p.m., can be an effective and practical method for reducing UV exposure, however, the feasibility of this measure must be heavily studied. It is recommended that outdoor tasks be scheduled for the early morning or late afternoon, wherever feasible. It is of the utmost importance to educate workers about the risks associated with UV exposure. It is recommended that regular training sessions be conducted to ensure that all employees are aware of the dangers of UVR, how to recognise the early signs of skin damage, and the importance of using protective measures. Training may encompass demonstrations of the correct application of sunscreen and the advantages of wearing protective clothing.

The fostering of a workplace culture that prioritises UV protection requires the consistent reinforcement of such a culture by management. It is incumbent upon employers to set an example by actively participating in UV protection measures and acknowledging those workers who adhere to protective practices. The use of regular reminders, such as posters or digital messages, can assist in maintaining a focus on UV safety.

The implementation of a system through which workers can report concerns or incidents related to UV exposure can facilitate the monitoring of the efficacy of preventive measures and the implementation of necessary adjustments. The incorporation of periodic health checks focusing on skin health can also constitute a component of this monitoring process.

Furthermore, the introduction of an insurance-based mechanism for outdoor workers to benefit from dermatological screenings could be considered. This could entail the linkage of insurance coverage to regular check-ups, with accountability for attendance also ensured. This approach would encourage both employers and employees to prioritise skin health, providing a structured way to manage and monitor UV exposure risks while fostering proactive health management. The integration of these strategies enables employers to establish a safer work environment that minimises the risk of NMSC, thereby promoting the health and well-being of outdoor workers across diverse occupational settings.

Suggestions for Future Research

As our comprehension of the risks associated with NMSC and exposure to solar UVR among those engaged in outdoor occupations deepens, it becomes evident that further research is imperative to examine these risks in a more comprehensive manner across diverse populations. A number of factors, including genetic predisposition, skin type and environmental conditions, can have a significant impact on the incidence of NMSC (and SCC). It is recommended that future studies focus on these diverse populations in order to develop tailored prevention strategies, ensuring that protective measures are effective and inclusive.

Based on all that was mentioned throughout this paper, we intend to, in the future, develop a more accurate formula that calculates the RR of developing SCC for application in occupational settings, in which we optimize the formula developed by Milon *et al.* for this purpose. The new model would include the inclusion of several other variables, such as skin phototype according to the Fitzpatrick scale, genetic predisposition, confounding factors, and other factors considered relevant. The first phase of this study is already being planned, as the model will also include a dermatological screening section. To ensure the efficiency of the screening programs, it is crucial to establish specific criteria for determining eligible individuals- this will be detailed in said study, as developing a tailored predictive model to identify those most susceptible to SCC is crucial. This approach not only improves screening eligibility but also enhances targeted and efficient SCC prevention, thereby significantly reducing morbidity and mortality related to SCC.

Eventually, and if feasible based on the resulting data and outcomes, we will develop an artificial intelligence learning tool/ system for the prediction of NMSC development. This system will serve as a tool for NMSC screening, assisting in identifying and referencing patients who are at risk. It will also support the development of better protection options and help policymakers formulate occupational medicine policies. In addition, this study could also allow the development of wearable sensors or smartphone apps, which are able to monitor UVR exposure more accurately during work hours.

Furthermore, and in a near future, it might be helpful to enhance the results of the MEAOW study by comparing the findings of said paper with other populations or regions within Portugal, particularly in areas with different climates or UV exposure patterns.

Additionally, we suggest a longitudinal study to track UVR exposure and NMSC incidence over time in outdoor workers.

Based on the proposed future studies and the policies suggested, it would also be relevant to develop a study that measures UVR dose of outdoor workers who comply with safety regulations versus those who do not, in order to evaluate the effectiveness of different preventive measures, such as the impact of specific types of protective clothing, or the benefits of workplace policies that limit UV exposure.

Broader Implications

The present study contributes to our understanding of the health risks associated with solar UVR and the prevention of NMSC, more specifically SCC, among individuals engaged in outdoor work. The findings indicate an elevated risk of SCC development among these individuals, underscoring the necessity for enhanced protective measures and occupational policy development. The results of this study have significant implications for the advancement of public health strategies in Portugal, particularly in the domains of epidemiology, public health, and occupational health, as well as clinical research.

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Appendix

Milon's Model Assumptions- The SimUVEx Model

In order to gain insight into, and quantify the degree of UVR exposure experienced by an individual engaged in outdoor work, Milon and colleagues (34) employed the SimUVEx model, a computer-based tool designed to assess the extent to which UVR radiation from the sun reaches various regions of the body. More information regarding this model may be found in the appendix section. It is important, however, to consider that the manikin was positioned in a manner that mimicked the positions that an outdoor worker is often found in, and the data input into the model was from a weather station in Switzerland. The model generates a three-dimensional representation of the individual, incorporating factors such as posture, body orientation towards the sun, and the presence and position of shadows cast by other body parts. The resulting data is typically presented in graphical form, as illustrated in Figure 3.

To ensure accuracy, the model requires five inputs: direct sunlight, sunlight reflected off the ground, the sun's position in the sky, and scattered sunlight (42). The latter represents sunlight that has undergone deflection in multiple directions following its interaction with molecules and particles within the Earth's atmosphere (42). This phenomenon contributes to the overall brightness of the sky, even in regions not directly illuminated by the sun (42).

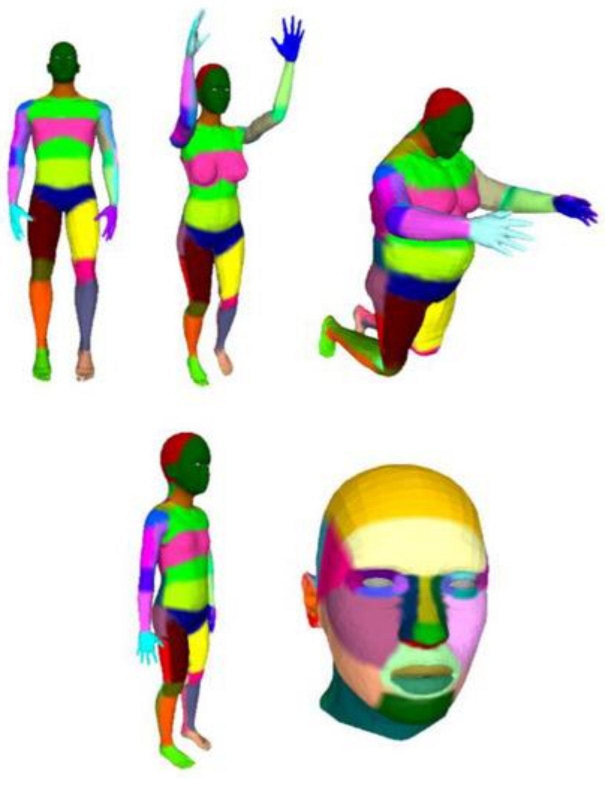

Figure 5 The five morphologies of SimUVEx: (on the top) adult man, adult woman, heavy man; (on the bottom) child, head-form. Each colour represents an anatomical zone. Source: Reference 42.

In the study developed by Milon et al., the relevant data for the SIMUVEx model was obtained from a weather station in Switzerland that records UV levels at one-minute intervals (34). The data set was derived from the entirety of the year 2012. Any missing data was estimated through recalculation based on the available measurements (34). In the event of any absence or inaccuracy in the data pertaining to direct, diffuse, or reflected sunlight, the researchers employed the data on total ground irradiance (i.e., the overall sunlight reaching the ground) to make the requisite estimates (34). By employing this supplementary information, the researchers were able to address the missing data points and guarantee comprehensive coverage of the data set, thus ensuring accurate analysis. The results were analysed using the dedicated software program Stata/IC 12.0 (StataCorp LP, College Station, TX, USA) (34).

Concerning In the study conducted by Milon et al. (34), the SimUVEx model manikin was positioned in a stationary state with its arms extended and slowly rotating in a circular motion (34). This configuration was considered to replicate the typical movements of outdoor workers who, due to the nature of their jobs, are not exposed to a specific direction of sunlight/ UVR throughout the course of their workday.

The researchers focused their attention on two primary categories of daily UV exposure. The first category of exposure was designated as "workday doses," which encompassed the period between 8:00 a.m. and 12:00 p.m., as well as the interval between 1:00 PM and 5:00 PM, both inclusive. The second category of exposure was designated as "lunch break doses," which encompassed the period between 12:00 p.m. and 1:00 p.m. The researchers assumed that the skin was unprotected, thereby representing the maximum possible UV exposure.

To calculate the exposure, the researchers conducted 732 simulations, with two simulations conducted for each day of 2012 (which had 366 days). This was done to determine the extent of UV radiation received by different body parts throughout the year. The exposure was classified into three categories, namely high, moderate, and low, based on the frequency of time spent outdoors. To illustrate, an individual engaged in indoor work who occasionally ventures outside, such as an office worker who consumes their lunch in an outdoor setting, would be considered to have low exposure. Those engaged in regular outdoor work, such as a construction supervisor, were found to have a moderate exposure, while full-time outdoor workers, such as construction workers and gardeners, exhibited high exposure. Furthermore, the study considered a seasonal scenario for individuals who spend a sizeable portion of their time outdoors only during specific periods, such as during a summer vacation, which is not relevant for the present study.

The results measured both the daily and yearly UV doses for different body parts and examined the frequency with which a safe dose of UV radiation was exceeded throughout the year.

Summary of Data (MEAOW study)

Table 5 Erythemal ultraviolet radiation (UVR) exposure (J/m2) measured for outdoor workers of six occupations

Occupation	Number of days with dosimeter	Number of hours with dosimeter	Average UV dose (J/m2)	Standard deviation (J/m2)	Maximum value captured	Minimum value captured	UV dose (J/m2) per hour
Gravedigger	17	117	287.2152941	87.1850456	423.32	140.41	2.455
Gravedigger	103	752	297.9087379	238.8064024	1097.58	6.73	0.396
Gravedigger	115	833	289.0116522	307.8665216	1559.87	22.63	0.347
Gravedigger	105	771	194.7988571	134.8182425	559.8	13.76	0.253
Gravedigger	130	952	491.8185385	419.3203082	1642.09	79.04	0.517
Gravedigger	95	648	214.1858947	189.5674148	834.19	0.03	0.331
Gravedigger	69	466	248.1985507	138.6718787	525.5	0	0.533
Gravedigger	134	904	204.6509701	126.9907035	632.53	15.43	0.226
Gravedigger	6	44	184.4516667	63.83062789	296.65	113.79	4.192
Gravedigger	80	561	205.09875	117.2253714	482.52	0.06	0.366
Pavers	110	838	23.12227273	35.98678954	172.57	1.55	0.028
Pavers	109	795	47.6693578	62.89543682	271.87	1.16	0.060
Pavers	216	1663	13.47615741	54.77948056	539.23	0.39	0.008
Pavers	199	1503	32.04959799	50.50115495	248.76	0.23	0.021
Pavers	4	31	270.495	94.14176703	409.86	206.82	8.726
Gardener	27	211	276.5492593	119.8458903	564.07	60.83	1.311
Gardener	17	132	329.9605882	112.0749735	619.6	147.73	2.500
Gardener	69	525	255.1444928	173.538922	878.98	5.34	0.486
Gardener	26	195	130.1715385	134.8878761	338	3.16	0.668
Gardener	36	269	358.185	143.8048311	682.12	51.11	1.332

Gardener	24	191	170.76625	47.41561665	271.09	86.73	0.894
Gardener	24	177	131.88	186.1727755	675.9	0.36	0.745
Gardener	145	1125	224.8708966	136.1258173	712.99	13.1	0.200
Gardener	20	149	239.1965	105.7572617	477.9	46.91	1.605
Gardener	89	636	300.2353933	166.0645915	743.13	10.06	0.472
Sanitation	71	532	241.3014085	207.0070519	749.7	2.03	0.454
Sanitation	126	953	189.3094444	190.3365286	924.98	4.31	0.199
Sanitation	103	767	128.2042718	89.27776515	354.83	7	0.167
Sanitation	84	627	146.504881	112.6303351	396.34	0.22	0.234
Sanitation	114	864	213.9495614	165.092635	697.2	1.54	0.248
Sanitation	126	939	238.2265079	184.8851985	915.34	2.56	0.254
Sanitation	95	719	235.8106316	177.5734324	671.91	9.06	0.328
Sanitation	112	849	307.7360714	202.5900913	853.81	29.41	0.362
Asphalters	74	566	92.685	61.88048433	242.21	0	0.164
Asphalters	120	937	59.35891667	100.4411828	333.27	0.75	0.063
Asphalters	34	256	89.63705882	68.41392475	251.47	7.97	0.350
Asphalters	61	430	223.3898361	137.2520559	449.36	5.56	0.520
Asphalters	86	645	160.1936047	340.9606358	1833.43	0.15	0.248
Asphalters	25	99	143.5532	139.0962037	422.65	3.59	1.450
Asphalters	59	440	47.05355932	57.55181203	217.15	0.04	0.107
Asphalters	71	520	117.4073239	77.60986011	320.81	1.39	0.226
Sailor	25	161	453.9232	324.3328837	1253.83	20.24	2.819

Cumulative UVR dose- 1 year

Table 6 Annual Occupational UV Exposure Metrics for outdoor workers in Lisbon, considering they work 8 hours per day and have one hour for lunch (9h workdays)

Occupation	Dosimeter	UV dose (J/m2) per hour	UV dose (J/m2) per working day (8+1h)	UV dose (J/m2) per year (239 days)- Yearly cumulative UV dose	SED per year (239 days)
Gravedigger	PRT-2023-900-001	2.455	22.093	5280.343	52.803
Gravedigger	PRT-2023-900-002	0.396	3.565	852.130	8.521
Gravedigger	PRT-2023-900-003	0.347	3.123	746.295	7.463
Gravedigger	PRT-2023-900-004	0.253	2.274	543.466	5.435
Gravedigger	PRT-2023-900-005	0.517	4.650	1111.241	11.112
Gravedigger	PRT-2023-900-006	0.331	2.975	710.978	7.110
Gravedigger	PRT-2023-900-007	0.533	4.794	1145.655	11.457
Gravedigger	PRT-2023-900-008	0.226	2.037	486.952	4.870
Gravedigger	PRT-2023-900-009	4.192	37.729	9017.171	90.172
Gravedigger	PRT-2023-900-010	0.366	3.290	786.395	7.864
Pavers	PRT-2023-900-011	0.028	0.248	59.351	0.594
Pavers	PRT-2023-900-014	0.060	0.540	128.977	1.290
Pavers	PRT-2023-900-016	0.008	0.073	17.431	0.174
Pavers	PRT-2023-900-018	0.021	0.192	45.867	0.459
Pavers	PRT-2023-900-019	8.726	78.531	18768.863	187.689
Gardener	PRT-2023-900-021	1.311	11.796	2819.230	28.192
Gardener	PRT-2023-900-022	2.500	22.497	5376.858	53.769
Gardener	PRT-2023-900-023	0.486	4.374	1045.363	10.454
Gardener	PRT-2023-900-024	0.668	6.008	1435.892	14.359

Gardener	PRT-2023-900-025	1.332	11.984	2864.148	28.641
Gardener	PRT-2023-900-026	0.894	8.047	1923.132	19.231
Gardener	PRT-2023-900-027	0.745	6.706	1602.677	16.027
Gardener	PRT-2023-900-028	0.200	1.799	429.953	4.300
Gardener	PRT-2023-900-029	1.605	14.448	3453.098	34.531
Gardener	PRT-2023-900-030	0.472	4.249	1015.419	10.154
Sanitation	PRT-2023-900-031	0.454	4.082	975.638	9.756
Sanitation	PRT-2023-900-032	0.199	1.788	427.287	4.273
Sanitation	PRT-2023-900-033	0.167	1.504	359.540	3.595
Sanitation	PRT-2023-900-034	0.234	2.103	502.603	5.026
Sanitation	PRT-2023-900-035	0.248	2.229	532.645	5.326
Sanitation	PRT-2023-900-036	0.254	2.283	545.714	5.457
Sanitation	PRT-2023-900-037	0.328	2.952	705.464	7.055
Sanitation	PRT-2023-900-038	0.362	3.262	779.671	7.797
Asphalters	PRT-2023-900-039	0.164	1.474	352.236	3.522
Asphalters	PRT-2023-900-040	0.063	0.570	136.266	1.363
Asphalters	PRT-2023-900-041	0.350	3.151	753.161	7.532
Asphalters	PRT-2023-900-042	0.520	4.676	1117.469	11.175
Asphalters	PRT-2023-900-043	0.248	2.235	534.227	5.342
Asphalters	PRT-2023-900-044	1.450	13.050	3119.020	31.190
Asphalters	PRT-2023-900-045	0.107	0.962	230.028	2.300
Asphalters	PRT-2023-900-046	0.226	2.032	485.660	4.857
Sailor	PRT-2023-900-048	2.819	25.375	6064.527	60.645

Cumulative UVR dose by occupation- 1 year

Table 7 UV dose (J/m2) per year (239 days)- Yearly cumulative UV dose- considering one working day to be of 9h (8+1)

Occupation	UV dose (J/m2) per year (239 days)- Yearly cumulative UV dose- considering 1 working day to be of 9h (8+1)	SED per year (239 days)
Gravedigger	2068.063	20.681
Paver	3804.098	38.041
Gardener	2196.577	21.966
Sanitation	603.570	6.036
Asphalters	841.008	8.410
Sailors	6064.527	60.645

Cumulative UVR dose- 25 years

Table 8 UV dose and SED over the course of 25 years, considering shifts of 7h plus one for lunch

Occupation	Dosimeter	UV dose (J/m2) per year (239 days)- Yearly cumulative UV dose	SED per year (239 days)	UV dose (J/m2) for 25 years- cumulative UV dose	Cumulative SED (25 years)
Gravedigger	PRT-2023-900-001	4693.638	46.936	117340.949	1173.409
Gravedigger	PRT-2023-900-002	757.449	7.574	18936.220	189.362
Gravedigger	PRT-2023-900-003	663.374	6.634	16584.342	165.843
Gravedigger	PRT-2023-900-004	483.081	4.831	12077.024	120.770

Gravedigger	PRT-2023-900-005	987.770	9.878	24694.250	246.943
Gravedigger	PRT-2023-900-006	631.981	6.320	15799.515	157.995
Gravedigger	PRT-2023-900-007	1018.360	10.184	25458.993	254.590
Gravedigger	PRT-2023-900-008	432.846	4.328	10821.146	108.211
Gravedigger	PRT-2023-900-009	8015.263	80.153	200381.583	2003.816
Gravedigger	PRT-2023-900-010	699.017	6.990	17475.437	174.754
Pavers	PRT-2023-900-011	52.756	0.528	1318.908	13.189
Pavers	PRT-2023-900-014	114.646	1.146	2866.158	28.662
Pavers	PRT-2023-900-016	15.494	0.155	387.348	3.873
Pavers	PRT-2023-900-018	40.771	0.408	1019.275	10.193
Pavers	PRT-2023-900-019	16683.434	166.834	417085.839	4170.858
Gardener	PRT-2023-900-021	2505.982	25.060	62649.548	626.495
Gardener	PRT-2023-900-022	4779.429	47.794	119485.728	1194.857
Gardener	PRT-2023-900-023	929.212	9.292	23230.299	232.303
Gardener	PRT-2023-900-024	1276.349	12.763	31908.716	319.087
Gardener	PRT-2023-900-025	2545.910	25.459	63647.743	636.477
Gardener	PRT-2023-900-026	1709.451	17.095	42736.266	427.363
Gardener	PRT-2023-900-027	1424.602	14.246	35615.051	356.151
Gardener	PRT-2023-900-028	382.181	3.822	9554.515	95.545
Gardener	PRT-2023-900-029	3069.421	30.694	76735.521	767.355
Gardener	PRT-2023-900-030	902.594	9.026	22564.861	225.649
Sanitation	PRT-2023-900-031	867.234	8.672	21680.841	216.808
Sanitation	PRT-2023-900-032	379.811	3.798	9495.269	94.953
Sanitation	PRT-2023-900-033	319.591	3.196	7989.784	79.898
Sanitation	PRT-2023-900-034	446.758	4.468	11168.953	111.690
Sanitation	PRT-2023-900-035	473.462	4.735	11836.561	118.366

Sanitation	PRT-2023-900-036	485.079	4.851	12126.972	121.270
Sanitation	PRT-2023-900-037	627.079	6.271	15676.979	156.770
Sanitation	PRT-2023-900-038	693.040	6.930	17326.012	173.260
Asphalters	PRT-2023-900-039	313.098	3.131	7827.461	78.275
Asphalters	PRT-2023-900-040	121.125	1.211	3028.128	30.281
Asphalters	PRT-2023-900-041	669.477	6.695	16736.920	167.369
Asphalters	PRT-2023-900-042	993.306	9.933	24832.638	248.326
Asphalters	PRT-2023-900-043	474.868	4.749	11871.712	118.717
Asphalters	PRT-2023-900-044	2772.462	27.725	69311.545	693.115
Asphalters	PRT-2023-900-045	204.469	2.045	5111.728	51.117
Asphalters	PRT-2023-900-046	431.698	4.317	10792.442	107.924
Sailor	PRT-2023-900-048	5390.690	53.907	134767.261	1347.673

Table 9 UV dose and SED over the course of 25 years, considering shifts of 8h plus one for lunch

Occupation	Dosimeter	UV dose (J/m2) per year (239 days)- Yearly cumulative UV dose	SED per year (239 days)	UV dose (J/m2) for 25 years- cumulative UV dose	Cumulative SED (25 years)
Gravedigger	PRT-2023-900-001	5280.343	52.803	132008.568	1320.086
Gravedigger	PRT-2023-900-002	852.130	8.521	21303.248	213.032
Gravedigger	PRT-2023-900-003	746.295	7.463	18657.385	186.574
Gravedigger	PRT-2023-900-004	543.466	5.435	13586.652	135.867
Gravedigger	PRT-2023-900-005	1111.241	11.112	27781.031	277.810
Gravedigger	PRT-2023-900-006	710.978	7.110	17774.454	177.745

Gravedigger	PRT-2023-900-007	1145.655	11.457	28641.367	286.414
Gravedigger	PRT-2023-900-008	486.952	4.870	12173.790	121.738
Gravedigger	PRT-2023-900-009	9017.171	90.172	225429.281	2254.293
Gravedigger	PRT-2023-900-010	786.395	7.864	19659.867	196.599
Pavers	PRT-2023-900-011	59.351	0.594	1483.771	14.838
Pavers	PRT-2023-900-014	128.977	1.290	3224.427	32.244
Pavers	PRT-2023-900-016	17.431	0.174	435.767	4.358
Pavers	PRT-2023-900-018	45.867	0.459	1146.685	11.467
Pavers	PRT-2023-900-019	18768.863	187.689	469221.569	4692.216
Gardener	PRT-2023-900-021	2819.230	28.192	70480.741	704.807
Gardener	PRT-2023-900-022	5376.858	53.769	134421.444	1344.214
Gardener	PRT-2023-900-023	1045.363	10.454	26134.086	261.341
Gardener	PRT-2023-900-024	1435.892	14.359	35897.305	358.973
Gardener	PRT-2023-900-025	2864.148	28.641	71603.711	716.037
Gardener	PRT-2023-900-026	1923.132	19.231	48078.299	480.783
Gardener	PRT-2023-900-027	1602.677	16.027	40066.932	400.669
Gardener	PRT-2023-900-028	429.953	4.300	10748.829	107.488
Gardener	PRT-2023-900-029	3453.098	34.531	86327.462	863.275
Gardener	PRT-2023-900-030	1015.419	10.154	25385.469	253.855
Sanitation	PRT-2023-900-031	975.638	9.756	24390.946	243.909
Sanitation	PRT-2023-900-032	427.287	4.273	10682.178	106.822
Sanitation	PRT-2023-900-033	359.540	3.595	8988.507	89.885
Sanitation	PRT-2023-900-034	502.603	5.026	12565.072	125.651
Sanitation	PRT-2023-900-035	532.645	5.326	13316.132	133.161
Sanitation	PRT-2023-900-036	545.714	5.457	13642.844	136.428
Sanitation	PRT-2023-900-037	705.464	7.055	17636.602	176.366

Sanitation	PRT-2023-900-038	779.671	7.797	19491.764	194.918
Asphalters	PRT-2023-900-039	352.236	3.522	8805.894	88.059
Asphalters	PRT-2023-900-040	136.266	1.363	3406.644	34.066
Asphalters	PRT-2023-900-041	753.161	7.532	18829.035	188.290
Asphalters	PRT-2023-900-042	1117.469	11.175	27936.717	279.367
Asphalters	PRT-2023-900-043	534.227	5.342	13355.676	133.557
Asphalters	PRT-2023-900-044	3119.020	31.190	77975.488	779.755
Asphalters	PRT-2023-900-045	230.028	2.300	5750.694	57.507
Asphalters	PRT-2023-900-046	485.660	4.857	12141.498	121.415
Sailor	PRT-2023-900-048	6064.527	60.645	151613.168	1516.132

RR and Increase in Risk of Developing SCC

Individual RR calculation

Table 10 RR of developing SCC when exposed to solar UVR for a total of 9 hours per day in an occupational setting

Occupation	Dosimeter	Cumulative SED (25 years)- 8h of work per day	Relative Risk
Gravedigger	PRT-2023-900-001	1320.086	1.196
Gravedigger	PRT-2023-900-002	213.032	1.030
Gravedigger	PRT-2023-900-003	186.574	1.026
Gravedigger	PRT-2023-900-004	135.867	1.019
Gravedigger	PRT-2023-900-005	277.810	1.039
Gravedigger	PRT-2023-900-006	177.745	1.025
Gravedigger	PRT-2023-900-007	286.414	1.041

Gravedigger	PRT-2023-900-008	121.738	1.017
Gravedigger	PRT-2023-900-009	2254.293	1.347
Gravedigger	PRT-2023-900-010	196.599	1.028
Pavers	PRT-2023-900-011	14.838	1.002
Pavers	PRT-2023-900-014	32.244	1.005
Pavers	PRT-2023-900-016	4.358	1.001
Pavers	PRT-2023-900-018	11.467	1.002
Pavers	PRT-2023-900-019	4692.216	1.794
Gardener	PRT-2023-900-021	704.807	1.102
Gardener	PRT-2023-900-022	1344.214	1.199
Gardener	PRT-2023-900-023	261.341	1.037
Gardener	PRT-2023-900-024	358.973	1.051
Gardener	PRT-2023-900-025	716.037	1.104
Gardener	PRT-2023-900-026	480.783	1.069
Gardener	PRT-2023-900-027	400.669	1.057
Gardener	PRT-2023-900-028	107.488	1.015
Gardener	PRT-2023-900-029	863.275	1.126
Gardener	PRT-2023-900-030	253.855	1.036
Sanitation	PRT-2023-900-031	243.909	1.035
Sanitation	PRT-2023-900-032	106.822	1.015
Sanitation	PRT-2023-900-033	89.885	1.013
Sanitation	PRT-2023-900-034	125.651	1.018
Sanitation	PRT-2023-900-035	133.161	1.019
Sanitation	PRT-2023-900-036	136.428	1.019
Sanitation	PRT-2023-900-037	176.366	1.025
Sanitation	PRT-2023-900-038	194.918	1.028

Asphalters	PRT-2023-900-039	88.059	1.012
Asphalters	PRT-2023-900-040	34.066	1.005
Asphalters	PRT-2023-900-041	188.290	1.027
Asphalters	PRT-2023-900-042	279.367	1.040
Asphalters	PRT-2023-900-043	133.557	1.019
Asphalters	PRT-2023-900-044	779.755	1.113
Asphalters	PRT-2023-900-045	57.507	1.008
Asphalters	PRT-2023-900-046	121.415	1.017
Sailor	PRT-2023-900-048	1516.132	1.226

RR by percentage of body exposed

Table 11 RR of developing SCC in both 8 hour and 9-hour shifts, considering that, during a work hours, only 0.124m2 of the total body area is exposed to solar UVR

Occupation	Dosimeter	UV dose (J/m2) per year (239 days) considering 0.124m^2 of body is exposed (8h)	Cumulative SED (25 years- 8h per day)	RR (8h)	UV dose (J/m2) per year (239 days) considering 0.124m^2 of body is exposed (9h)	Cumulative SED (25 years- 9h per day)	RR (9h)
Gravedigger	PRT-2023-900-001	582.01	145.50	1.021	654.76	163.69	1.023
Gravedigger	PRT-2023-900-002	93.92	23.48	1.003	105.66	26.42	1.004
Gravedigger	PRT-2023-900-003	82.26	20.56	1.003	92.54	23.14	1.003
Gravedigger	PRT-2023-900-004	59.90	14.98	1.002	67.39	16.85	1.002

Gravedigger	PRT-2023-900-005	122.48	30.62	1.004	137.79	34.45	1.005
Gravedigger	PRT-2023-900-006	78.37	19.59	1.003	88.16	22.04	1.003
Gravedigger	PRT-2023-900-007	126.28	31.57	1.004	142.06	35.52	1.005
Gravedigger	PRT-2023-900-008	53.67	13.42	1.002	60.38	15.10	1.002
Gravedigger	PRT-2023-900-009	993.89	248.47	1.035	1118.13	279.53	1.040
Gravedigger	PRT-2023-900-010	86.68	21.67	1.003	97.51	24.38	1.003
Pavers	PRT-2023-900-011	6.54	1.64	1.000	7.36	1.84	1.000
Pavers	PRT-2023-900-014	14.22	3.55	1.000	15.99	4.00	1.001
Pavers	PRT-2023-900-016	1.92	0.48	1.000	2.16	0.54	1.000
Pavers	PRT-2023-900-018	5.06	1.26	1.000	5.69	1.42	1.000
Pavers	PRT-2023-900-019	2068.75	517.19	1.074	2327.34	581.83	1.084
Gardener	PRT-2023-900-021	310.74	77.69	1.011	349.58	87.40	1.012
Gardener	PRT-2023-900-022	592.65	148.16	1.021	666.73	166.68	1.024
Gardener	PRT-2023-900-023	115.22	28.81	1.004	129.63	32.41	1.005

Gardener	PRT-2023-900-024	158.27	39.57	1.006	178.05	44.51	1.006
Gardener	PRT-2023-900-025	315.69	78.92	1.011	355.15	88.79	1.013
Gardener	PRT-2023-900-026	211.97	52.99	1.007	238.47	59.62	1.008
Gardener	PRT-2023-900-027	176.65	44.16	1.006	198.73	49.68	1.007
Gardener	PRT-2023-900-028	47.39	11.85	1.002	53.31	13.33	1.002
Gardener	PRT-2023-900-029	380.61	95.15	1.013	428.18	107.05	1.015
Gardener	PRT-2023-900-030	111.92	27.98	1.004	125.91	31.48	1.004
Sanitation	PRT-2023-900-031	107.54	26.88	1.004	120.98	30.24	1.004
Sanitation	PRT-2023-900-032	47.10	11.77	1.002	52.98	13.25	1.002
Sanitation	PRT-2023-900-033	39.63	9.91	1.001	44.58	11.15	1.002
Sanitation	PRT-2023-900-034	55.40	13.85	1.002	62.32	15.58	1.002
Sanitation	PRT-2023-900-035	58.71	14.68	1.002	66.05	16.51	1.002
Sanitation	PRT-2023-900-036	60.15	15.04	1.002	67.67	16.92	1.002
Sanitation	PRT-2023-900-037	77.76	19.44	1.003	87.48	21.87	1.003

Sanitation	PRT-2023-900-038	85.94	21.48	1.003	96.68	24.17	1.003
Asphalters	PRT-2023-900-039	38.82	9.71	1.001	43.68	10.92	1.002
Asphalters	PRT-2023-900-040	15.02	3.75	1.001	16.90	4.22	1.001
Asphalters	PRT-2023-900-041	83.02	20.75	1.003	93.39	23.35	1.003
Asphalters	PRT-2023-900-042	123.17	30.79	1.004	138.57	34.64	1.005
Asphalters	PRT-2023-900-043	58.88	14.72	1.002	66.24	16.56	1.002
Asphalters	PRT-2023-900-044	343.79	85.95	1.012	386.76	96.69	1.014
Asphalters	PRT-2023-900-045	25.35	6.34	1.001	28.52	7.13	1.001
Asphalters	PRT-2023-900-046	53.53	13.38	1.002	60.22	15.06	1.002
Sailor	PRT-2023-900-048	668.45	167.11	1.024	752.00	188.00	1.027

Summary of RR and Increase in Risk of Developing SCC

Table 12 Increased risk (%) of developing SCC, based on the RR

Occupation	Dosimeter	Days using dosimeter	RR	Increased risk (%)
Gravedigger	PRT-2023-900-001	17	1.173	17%
Gravedigger	PRT-2023-900-002	103	1.027	3%

Gravedigger	PRT-2023-900-003	115	1.023	2%
Gravedigger	PRT-2023-900-004	105	1.017	2%
Gravedigger	PRT-2023-900-005	130	1.035	4%
Gravedigger	PRT-2023-900-006	95	1.022	2%
Gravedigger	PRT-2023-900-007	69	1.036	4%
Gravedigger	PRT-2023-900-008	134	1.015	2%
Gravedigger	PRT-2023-900-009	6	1.305	31%
Gravedigger	PRT-2023-900-010	80	1.025	2%
Pavers	PRT-2023-900-011	110	1.002	0.2%
Pavers	PRT-2023-900-014	109	1.004	0.4%
Pavers	PRT-2023-900-016	216	1.001	0.1%
Pavers	PRT-2023-900-018	199	1.001	0.1%
Pavers	PRT-2023-900-019	4	1.692	69%
Gardener	PRT-2023-900-021	27	1.090	9%
Gardener	PRT-2023-900-022	17	1.176	18%
Gardener	PRT-2023-900-023	69	1.033	3%
Gardener	PRT-2023-900-024	26	1.045	5%
Gardener	PRT-2023-900-025	36	1.092	9%
Gardener	PRT-2023-900-026	24	1.061	6%
Gardener	PRT-2023-900-027	24	1.051	5%
Gardener	PRT-2023-900-028	145	1.013	1%
Gardener	PRT-2023-900-029	20	1.111	11%
Gardener	PRT-2023-900-030	89	1.032	3%
Sanitation	PRT-2023-900-031	71	1.031	3%
Sanitation	PRT-2023-900-032	126	1.013	1%
Sanitation	PRT-2023-900-033	103	1.011	1%

Sanitation	PRT-2023-900-034	84	1.016	2%
Sanitation	PRT-2023-900-035	114	1.017	2%
Sanitation	PRT-2023-900-036	126	1.017	2%
Sanitation	PRT-2023-900-037	95	1.022	2%
Sanitation	PRT-2023-900-038	112	1.024	2%
Asphalters	PRT-2023-900-039	74	1.011	1%
Asphalters	PRT-2023-900-040	120	1.004	0.4%
Asphalters	PRT-2023-900-041	34	1.024	2%
Asphalters	PRT-2023-900-042	61	1.035	4%
Asphalters	PRT-2023-900-043	86	1.017	2%
Asphalters	PRT-2023-900-044	25	1.100	10%
Asphalters	PRT-2023-900-045	59	1.007	1%
Asphalters	PRT-2023-900-046	71	1.015	2%
Sailor	PRT-2023-900-048	25	1.200	20%

Additional Information

Table 13 Number of days that dosimeters logged data in comparison to the number of days considering the dosimeters were worn for 8h working shifts each day

Number of days using dosimeter	Number of days if dosimeter was worn during an entire 8h shift
17	15
103	94
115	104
105	96
130	119

95	81
69	58
134	113
6	6
80	70
110	105
109	99
216	208
199	188
4	4
27	26
17	17
69	66
26	24
36	34
24	24
24	22
145	141
20	19
89	80
71	67
126	119
103	96
84	78
114	108
126	117

95	90
112	106
74	71
120	117
34	32
61	54
86	81
25	12
59	55
71	65
25	20