SOLAR ULTRAVIOLET RADIATION AND OUTDOOR WORKERS IN CANADA: 
A PROGRAM OF RESEARCH ON EXPOSURE ASSESSMENT, SUN PROTECTION BEHAVIOURS AND 
PROSTATE CANCER RISK

by

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Abstract

Background: Exposure to solar ultraviolet radiation (UVR) is the main cause of skin cancer, and emerging evidence shows that it may prevent prostate cancer. Understanding the etiology of skin cancer has been challenged by a lack of detailed exposure assessment instruments, and this influences the ability to study the effect of solar radiation on other, more multi-factorial diseases.

Methods: In the first study (Chapters 3 and 4), 78 outdoor workers wore UVR dosimetry badges for five work days, and provided information on skin cancer risk factors and sun protective behaviours. This data was used to investigate levels of exposure and prevention behaviours. The second study (Chapters 2 and 5) developed a job exposure matrix (JEM) based on occupation/industry, time spent outdoors and satellite data on available ambient UVR. The JEM was used to investigate the risk of prostate cancer in outdoor workers using a previously conducted population-based case-control study.

Results: Over 300 UVR measurements were taken among seventy-three workers. Exposure was variable; the main predictors of exposure were time spent outdoors and meteorology. Outdoor workers relied more on clothing (hats, shirts) than on shade or sunscreen for protection. Sun protection scores showed that fairer people used more protection. The job sites’ clothing requirements also influenced protective behaviours. Based on the JEM, approximately 1.5 million Canadians (82% male) were exposed to solar UVR at work (for ≥2 hours/day). The largest exposed groups were construction workers, farmers and landscapers. Prostate cancer cases (n=1638) were compared to controls (n=1697) using the UVR satellite data-enhanced JEM and case status from national cancer registries. A statistically significant decrease in risk of prostate cancer was found in the highest exposed workers.

Conclusions: Outdoor workers in Canada experience high levels of solar UVR exposure. Sun protection was relatively high and was driven by workplace requirements, which suggests company policies requiring hats and shirts could be an effective prevention strategy. JEMs are a key tool for population-level studies, and the addition of objective measures into the matrix for solar UV radiation was an innovation that showed high, long-term occupational exposure to solar UVR is protective for prostate cancer.
Preface

Identification and design of the research program
The research topic and research design were developed by the candidate, with input and support from the thesis committee and paper co-authors. In particular, the Outdoor Workers Project was conceived of by the candidate, including the study design and tool selection. The National Enhanced Cancer Surveillance System study was performed by The Canadian Cancer Registries Epidemiology Research Group, and the data from this study was obtained with permission by the candidate. The UVR exposure linkage for the cases and controls was done by the candidate. Four research chapters (Chapters 2 to 5) were written as manuscripts for publication in peer-reviewed journals.

Performance of the research
Data collection protocols for the Outdoor Workers Project were designed and pilot tested by the candidate, and the study itself was carried out by the candidate without field assistance, with guidance from the thesis committee. The other components of the research (design of a job exposure matrix for outdoor workers, and the case-control study of prostate cancer) were also performed by the candidate with input and supervision from the thesis committee, in particular Dr. Koehoorn and Dr. Demers.

Data analysis
The analysis plan, which included data cleaning, compilation, and statistical analysis was developed by the candidate with regular review and advice from the thesis committee. All work thereafter was carried out by the candidate according to the analysis plan.

Publications
Chapters 2 through 5 were all prepared with the goal of submission as manuscripts. All outlines and drafts were prepared solely by the candidate and then circulated for review by the thesis committee, and one to two rounds of revisions occurred for each Chapter.

A version of Chapter 2 has been published. Peters CE, Nicol AM, Demers PA. (2012) ‘Prevalence of exposure to solar ultraviolet radiation (UVR) on the job in Canada.’ Canadian Journal of Public Health. 103(3):223-226. The candidate performed all the research for this manuscript and wrote the complete draft. Dr. Nicol and Dr. Demers contributed suggestions for revisions of some writing and tables. Total contribution to the work as a whole by the candidate was 85%.

A version of Chapter 4 has been submitted for publication. Peters CE, Demers PA, Kalia S, Nicol AM, Koehoorn MW. ‘Levels of occupational exposure to solar ultraviolet radiation in Vancouver, Canada.’ Submitted April, 2015. The candidate performed all data cleaning, coding, and statistical analyses and interpretation of the results, as well as preparation of the manuscript, with guidance from the committee. Total contribution to the work as a whole by the candidate was 80%.
Versions of Chapters 3 and 5 are in preparation.

**Ethics**

The Outdoor Workers Project was approved by the University of British Columbia’s Behavioural Research Ethics Board, certificate number H11 – 01272. It was initially approved on December 5\textsuperscript{th}, 2012, and was renewed through to September 3, 2015.
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List of Abbreviations

UVR: Ultraviolet radiation

nm: Nanometers, a unit of wavelength

W/m²: Watts per square meter, a unit of irradiance

J/m²: Joules per square meter, unit used for UVR dose

SED: Standard Erythemal Dose

glUV: Refers to the Global UV project, where ambient UVR data at the earth’s surface is made available

SCC: Squamous cell carcinoma (a form of skin cancer)

BCC: Basal cell carcinoma (a form of skin cancer; the most common form)

NMSC: Non-melanoma skin cancer: SCC and BCC together

NASA: National Aeronautics and Space Adminstration

NECSS: National Enhanced Cancer Surveillance System (case-control study)

CIE: Commission Internationale de l’Eclairage (International Commission on Illumination)

JEM: Job exposure matrix

NSS2: The Second National Sun Survey (Canada)
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Dedication

I would like to dedicate this thesis to my family: my supportive parents Dawn and Bruce Peters, my late grandmother Ann McCowan, my brothers Adam and John, my ‘sister’ Jennifer, and my partner Adam Lind. I could not have done this without you, nor would I have wanted to.
Chapter 1: Introduction and background

Skin cancer is the most common malignancy in the world, and Canada is no exception. In 2014, over 80,000 of the 270,000 newly diagnosed cancers in Canada were skin cancer [1]. Despite the fact that skin cancer is largely preventable (by limiting ultraviolet radiation [UVR] exposure), incidence is increasing in Canada [2]. The economic burden of skin cancer in Canada is currently estimated at $500 million, and even conservative projections predict this will double by the year 2031 if incidence trends continue [2].

Outdoor workers are a group at particular risk of prolonged and intense UVR exposure [3]. Most research on occupational exposure to UVR has been done in Australia, and data on measured values of UVR for Canadian workers are not available.

As a complicating factor in skin cancer etiology, sun exposure is also necessary for maintaining human health, largely thought to be due to our reliance on the sun to produce vitamin D endogenously. Vitamin D has been implicated as a potentially protective factor for several cancers (including reducing incidence but also increased survivorship) [4]. Though experimental evidence exists for many cancers, the most convincing epidemiological evidence of the protective effect of sun is for colorectal cancer; more equivocal relationships have been noted in meta-analyses for breast, pancreatic and prostate cancer [5].

Prostate cancer is of particular interest as it is the most common malignancy (after skin cancer) in men, and yet very little is known about its risk factors. There are strong differences in incidence rates by country, suggesting that environmental exposures could be important in the etiology of prostate cancer [6]. If solar UVR exposure decreases the risk of prostate cancer, then there are important implications for outdoor workers and their sun exposure patterns. The impetus to study prostate cancer rather than breast cancer, given that both of them are common cancers in men and women, respectively, is that there is a strong occupational source of solar UVR for men, which is much less important for women as they make up a minority of outdoor workers.

Epidemiologic studies require accurate exposure assessment procedures to properly calculate risks, and measures of exposure are required for risk assessment; these data do not exist in Canada for UVR exposure. Calls have been made to focus on the primary prevention of skin cancer in Canada [7], but this is challenging when a baseline average level of exposure has not been established.

This dissertation includes a series of four studies that address the need for direct measures of UVR exposure among outdoor workers in Canada and the determinants of exposure, the construction of a job exposure matrix of UVR exposure for use in epidemiological studies, and the investigation of the association between UVR exposure and prostate cancer risk.
1.1 Ultraviolet radiation: physical and biological concepts

The purpose of this thesis is not an exhaustive review of the fields of health physics with respect to UVR and human biology, but some basic concepts in radiation science and measurement as well as some explanations of how solar UVR interacts with human cells for both positive and negative effects is a useful foundation for the studies in this dissertation.

1.1.1 Ultraviolet radiation concepts and measurements units

Ultraviolet radiation (UVR) refers to the segment of the electromagnetic spectrum between the wavelengths of 100 and 400 nanometers (nm); these wavelengths are shorter than visible light, but longer than X-rays. UVR is further divided into the ranges of UV-A (315-400nm), UV-B (280-315nm) and UV-C (100-280nm) in order of increasing intensity. UV-C is filtered by the ozone layer, and none of this harmful radiation reaches the earth’s surface.

The measurement of UVR is complicated by the fact that different wavelengths have different power to cause an effect in humans and other animals. An action spectrum is a function for a particular biological outcome (in this case, sunburn) that expresses the relative strength of radiation at each wavelength as a fraction of the strength at a standard wavelength. For UVR, the standard action spectrum \( E(\lambda) \) is that of McKinlay and Diffey, which was adopted by the Commission Internationale de l'Éclairage, (CIE, International Commission on Illumination) in 1987 \[8\]. The formula of the CIE action spectrum is:

1) \( E(\lambda) = 1 \) when 250 nm < \( \lambda \) < 298 nm,
2) \( E(\lambda) = 10^{0.094(298-\lambda)} \) when 298 nm < \( \lambda \) < 328 nm,
3) \( E(\lambda) = 10^{0.015(139-\lambda)} \) when 328 nm < \( \lambda \) < 400 nm.

The CIE action spectrum is depicted visually in Figure 1.1, where it can be seen that UV-B wavelengths are weighted more heavily than UV-A wavelengths, reflecting the fact that UV-B is largely responsible for sunburn, the biological effect that is being weighted. In fact, the global UV irradiance on earth is approximately 94% UV-A and 6% UV-B, but the erythemally-weighted irradiance is just 17% UV-A and 83% UV-B \[9\].

Irradiance is a radiometric (physical) concept that refers to power density or radiant flux received by a surface; putting the word spectral in front of it (as in the y-axis of Figure 1) simply conveys that there is a wavelength dependency of the irradiance; the unit of spectral irradiance is commonly Watts per square meter per wavelength. When integrated over the UV spectrum using the CIE weighting function, this gives the UV Index, a dimensionless quantity developed by Environment Canada for use in risk communication to the general public. One UV Index unit is equal to 25 mW/m\(^2\) \[10\]. When the UV Index is further integrated over time (e.g. a day of exposure outside), it gives a measure of radiant exposure, or UVR dose, usually in Joules/m\(^2\), or alternatively as a Standard Erythemal Dose (SED), a unitless quantity where one unit is equivalent to 100 J/m\(^2\) \[8, 9\].
1.1.2 UV radiation and health effects in humans

Ultraviolet radiation has a variety of positive and negative effects on human health via its interactions with different cells and structures in the skin. Lucas and Ponsonby [11] have postulated that solar UVR-related burden of disease is likely U-shaped, with adverse health outcomes such as bone-related diseases and rickets at extremely low doses of UVR, and skin cancers and eye diseases at high doses of UVR (Figure 1.2).

![Graph showing the CIE erythemal action spectrum with UV-B and UV-A labeling](image)

**Figure 1.1 The CIE erythemal action spectrum (black line)**

Vitamin D is a steroid pro-hormone that is important in the maintenance of bone health (it’s so called ‘classic’ function) [12]. Although a small amount of vitamin D is available in foods (e.g. fish, eggs, and fortified dairy products), the main source in humans is production in the skin following ultraviolet radiation (UVR) exposure, specifically UV-B [13]. Vitamin D₃ is manufactured in the skin through the breakdown of the ‘B’ bond in provitamin-D (7-dehydrocholesterol, 7-DHC), which is quickly converted into vitamin D₃ in the presence of body heat. This breakage of the ‘B’ bond is accomplished via exposure to UV-B radiation [14].
The hormonal form of vitamin D is produced via metabolic processes in the liver and kidney and is called calcitriol, or 1,25(OH)$_2$D$_3$ (the form measured to assess vitamin D levels in the blood and serum is derived from calcitriol and is denoted 25(OH)D$_3$) [4]. Calcitriol contributes to bone health by regulating calcium and phosphate homeostasis. Sufficient concentrations of calcitriol in the blood has been linked with decreased occurrence of rickets, osteoporosis, and bone fracture [12].

Vitamin D has other, non-skeletal functions in the body that are still under investigation, and these are linked to calcitriol’s ability to regulate gene transcription by binding to vitamin D receptors (VDR) [15]. The VDR is a transcription factor that is present in most cells in the body, and thus the activity of vitamin D is broad, and can affect immunity as well as the progression of some diseases [4, 16, 17]. Indeed, relationships between higher circulating calcitriol in the blood and decreased risk of rheumatoid arthritis, hypertension, multiple sclerosis, some cancers, and both Type I and II diabetes have been found [18]. This ability to produce provitamin D in the skin is reduced in those with more darkly pigmented skin and in the elderly, causing these populations to be at higher risk of vitamin D deficiency and its concomitant morbidities [18].

The amount of sun exposure required to produce enough vitamin D depends on skin type and sun protection behaviours at the individual level and latitude and other environmental factors more broadly, but for a Caucasian person with skin type II at midday in June at approximately
42° North latitude, only about 5 to 15 minutes of exposure to the arms and legs, three times per week should be more than enough to provide enough circulating vitamin D in the body to maintain health [19]. However, approximately 32% of Canadians have blood concentrations of vitamin D that are below the level considered sufficient for bone health (50 nmol/L) [20].

Ultraviolet radiation exposure also exerts negative effects in humans, primarily sunburn and skin cancer (the focus here), but also photoaging and several forms of eye damage (pterygium, cataract, squamous cell carcinoma of the cornea and conjunctiva, and photokeratitis and conjunctivitis) [21]. It is also suspected of causing immune system effects, and there is strong evidence that it can re-activate the herpes labialis virus. Ultraviolet radiation causes skin cancer by damaging DNA; UV-B is the primary component of UVR of concern for DNA damage, but UV-A can also cause damage DNA in indirect ways that are believed to be due to oxidative stress [22]. After DNA damage, if repair mechanisms fail, cell death or mutations in DNA result. This is not always a problem because large portions of DNA are underutilized, but if a mutation occurs at an oncogene or tumour suppressor gene, tumour development can then occur [22].

1.2 Risk factors for skin cancer

Skin cancer is a disease that develops in one of the two types of cells in the upper layer of the skin (the epidermis): skin cells (basal, squamous) and pigment-producing cells (melanocytes). Cancer in the melanocytes is called melanoma. The cancers in the skin cells are called basal and squamous cell carcinomas, and these latter two diseases together are referred to as non-melanoma skin cancer (NMSC).

Melanoma is the most dangerous type of skin cancer with respect to survival, and although it occurs much less frequently than NMSC, the incidence is increasing in fair-skinned populations more quickly than any other cancer worldwide [23]. A similar pattern of increasing incidence has also been seen for NMSC in white populations in Europe, the United States (US), Canada, and Australia, with an annual increase of approximately 3.8% per year [24].

All three types of skin cancer are related to increased exposure to UVR, though the pattern of exposure differs somewhat between the cancer types. Canadian estimates are not available, but in Australia 65-90% of melanoma is attributed to UVR, and in US whites, the attributable percentage is over 90% [25], including occupational sun exposure [26]. Melanoma is strongly linked with high doses of intermittent sunlight (causing sunburn), especially early in life [24]. Squamous cell carcinoma is more strongly linked to higher cumulative exposure, such as is seen in occupationally-exposed groups. More recently, basal cell carcinoma has also been linked more conclusively to occupational solar UVR exposure [27].

Many risk factors for skin cancer are related to variables associated with solar UV exposure. These include time of day (highest exposures are around midday), season (summer), latitude (exposure increases closer to the equator), cloud cover, altitude (higher altitude leads to higher exposure), ozone level (ozone absorbs UV radiation, so lower ozone leads to higher exposure) and ground reflection (reflective surfaces such as snow or water increase exposure) [28]. These
can be considered modifiable, as they can be at least partially mitigated by the use of appropriate sun protective behaviours. Other individual factors that increase the risk for skin cancer are pigmentation of the skin (light-skinned people are at higher risk), older age, presence of nevi (benign freckles or moles), genetic factors (i.e. melanoma risk is twice as high in those with a close relative with melanoma), and health-related factors (e.g. those on immunosuppressive drugs or who have had organ transplants are at higher risk of melanoma) [29]. Table 1 outlines the characteristics of different skin types as they relate to UV exposure and sun sensitivity.

Solar UV exposure also contributes to a number of other health concerns. Although rarely fatal, NMSC places people at risk of developing recurrent skin cancer, and also doubles the risk of other cancers [30]. Additional health risks from UVR exposure include eye problems (inflammatory and short term, or cataracts in the long-term), solar keratoses (benign skin lesions), and immune system effects [31].

Table 1.1 Skin pigmentation types [27, 39]

<table>
<thead>
<tr>
<th>Skin type (Fitzpatrick scale)</th>
<th>Example</th>
<th>Sun History</th>
<th>UVR dose causing burn on untanned skin (SED)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Pale white skin</td>
<td>Red-headed, freckles</td>
<td>Always burns, never tans, extremely sun sensitive</td>
<td>2 – 3</td>
</tr>
<tr>
<td>II. White</td>
<td>Fair-skinned, fair-haired, blue or green eyed, Caucasian</td>
<td>Always burns, rarely tans, very sun sensitive</td>
<td>2.5 – 3</td>
</tr>
<tr>
<td>III. White (Average)</td>
<td>Average Caucasian skin</td>
<td>Sometimes burns, tans gradually to light brown, sun sensitive</td>
<td>3 – 5</td>
</tr>
<tr>
<td>IV. Beige or lightly tanned</td>
<td>Mediterranean-type Caucasians</td>
<td>Burns minimally, always tans to moderate brown, minimally sun sensitive</td>
<td>4.5 – 6</td>
</tr>
<tr>
<td>V. Moderate brown or tanned</td>
<td>Middle Eastern, some Hispanics, some African-Americans</td>
<td>Rarely burns, tans well, sun insensitive</td>
<td>6 – 20</td>
</tr>
<tr>
<td>VI. Dark brown or black skin</td>
<td>African-Americans</td>
<td>Never burns, deeply pigmented, sun insensitive</td>
<td>6 – 20</td>
</tr>
</tbody>
</table>

*Standard Erythemal Dose

1.3 Risk factors for prostate cancer

Prostate cancer is the most common cancer diagnosis (after skin cancer) in Canada, with 23,600 cases diagnosed in 2014; 1 in 7 Canadian men are expected to develop prostate cancer in their lifetime [32]. Despite how common it is, the risk factors for the development of prostate cancer are not well known; the only established links are older age, racial background (main
relationship is higher risk in black populations, who also have lower vitamin D status on average), screening behaviours, and family history [33].

Due to geographic differences in prostate cancer rates (in particular a latitudinal gradient with lower risk closer to the equator), research interest has focused on potential environmental or occupational risk factors. Dietary factors and physical activity are suspected to contribute to at least some of the burden of prostate cancer, but consistent evidence to support this hypothesis is lacking [34]. Excess occupational risk factors have not been consistent, but industries with exposure to cadmium, herbicides, and fertilizers and those with low occupational physical activity have been implicated [35, 36]. Agricultural workers are a group with somewhat consistent findings of an increased risk, potentially linked to increased exposure to pesticides [36-38], however they also tend to have high occupational exposure to solar UVR, which may be a protective factor for prostate cancer [14]. Research from the Agricultural Health Study in the United States suggests that the potentially increased risk of Prostate cancer due to pesticide exposure could be affected quite strongly by genetic susceptibility, providing an explanation for the conflicting risk profiles observed among agricultural workers [39].

1.4 Occupational sun exposure

Outdoor workers (e.g. construction workers, fishermen, farmers, lifeguards, outdoor recreational staff, transportation, postal workers) are a group at high risk of prolonged and intense UVR exposure [3], and they are also a group of interest for prevention activities because they may have fewer options for avoidance or reduction of their sun exposure [40]. Outdoor workers also spend more of their leisure time in the sun than average [41]. Chapter 2 includes a detailed description of outdoor occupations in Canada.

The Canadian Second National Sun Survey (NSS2) found that 33% of workers in the Canadian province of British Columbia worked outdoors in the summer (67% for 2+ hours per day) [41], compared to the national average of 26%. In a workshop held post-survey, participants identified outdoor workers as key targets for UVR safety prevention efforts on [42]. This survey also reported that 5.4 million Canadians may work outdoors during the summer [40]. In addition, the first Canadian sun survey (1996) showed that outdoor workers report low levels of sun protection behaviors, similar to study findings in the US and Australia [43].

The risk of skin cancer from UV exposure varies with the type of cancer, as well as with the measure of sun exposure. Sun exposure can be divided into three categories: total (or lifetime) exposure, occupational exposure (continuous exposure over time), and recreational exposure (intermittent). Sunburn is often used as an indicator of high levels of intermittent exposure [29]. Occupational sun exposure is related to an increased risk for BCC and especially SCC, but not for melanoma (in fact, the relationship is inversed with melanoma) [29]. This should not be seen as evidence for a protective effect of UV exposure for melanoma. It is believed that this reflects an issue with the low-occupational exposure groups containing some (and sometimes many) people with high recreational sun exposure; thus the relationship simply reflects the association with recreational or intermittent exposure with melanoma [3, 29].
A few Canadian studies of skin cancer in outdoor workers have been completed, but they all assessed exposure to UV radiation by self-reported time spent outdoors throughout the working life, or using an occupational title only [44-47], or the studies were designed to look at beliefs and behaviours surrounding UV exposure and skin cancer prevention with no measure of actual exposure [43, 48].

1.5 Challenges in exposure assessment for solar UVR

The method used most often for estimating UV exposure has been self-reported time spent outside, using either questionnaires or personal diaries [49]. Results of epidemiologic studies using these metrics of exposure have been inconsistent probably due to the difficulty that people have estimating their time spent outside.

During sun exposure, the human body receives approximately 24 to 61% of the ambient radiation, depending upon time of day, duration of exposure, and the orientation of the body [50]. Variation in UV dose received is highly variable between individuals, likely due to behavioural and host factors [51]. There is a general lack of objective measures of UV exposure using personal dosimetry, and in particular for occupational exposure [52]. In a recent review and meta-analysis of the risk of SCC from occupational UV exposure, the authors located only 18 “high-quality” studies with reasonable exposure assessment, and none of these included any objective dosimetry measures, instead defining exposure using categories (i.e. “occupation mainly outdoors”), or estimated metrics based on self-reported behaviours and characteristics [53].

A recent review by Glanz and Mayer highlighted the objectivity, validity and reliability of self-report data used consistently in studies of UV exposure. Among other recommendations, increasing the use of personal dosimetry for UV exposure assessment was noted [54]. Indeed, workplace exposure has seldom been directly measured despite many recommendations to focus on outdoor workers as a key exposure group [52].

Objectively characterizing UV exposure to outdoor workers serves two broad purposes. The first is for appropriate risk assessment and scientific value: the more accurate the measures of a worker’s exposure to a hazard, the better the ability to model and identify exposure-response relationship in epidemiologic studies and for generating evidence to target prevention interventions. The second value of measuring exposure is that this information can be used in future studies to evaluate if prevention interventions reduce exposures. However, characterizing individual exposures to UVR for all participants in a large, population-based occupational studies is clearly not feasible; instruments that can accurately classify work-related sun exposure into meaningful exposure levels across occupational groups is warranted.

1.5.1 Personal exposure measurement concepts

Solar UVR can be objectively measured with a variety of instruments, classified broadly into chemical or physical detectors, and often containing filters for wavelength selection [55]. The
physical detectors rely on either a radiometric sensor that responds to the heating effect of radiation, or a photo-electric sensor that measure photons. The chemical sensors (often polysulfone) rely on a predictable colour-change reaction [55].

Measurements of UVR are typically expressed as Joules per square meter (J/m², a measure of energy), or Watts per square meter (W/m², a measure of power), incident on a surface area. The ability of UV radiation to burn human skin depends strongly on wavelength, and between the 250 and 400 nanometer wavelengths there is a four-fold difference in ability to harm [56]. Thus, there is a need to weight exposures depending on wavelength for exposure assessment. The standard way to do this is to use an erythemal (skin burning) action spectrum, and the commonly used function derived by the CIE (Commission Internationale de l'Eclairage, or International Commission on Illumination) [57]. Weighting exposure measures by wavelength using this CIE function allows the definition of a Standard Erythemal Dose (SED), which is equivalent to an erythemally-weighted effective exposure of 100 J/m². Doses are often expressed as an SED per day (SED_{day}) or as a percentage of the total available SED per day (SED_{max}).

1.5.2 Exposure assessment for UVR in population-based studies

A common instrument for exposure assessment in occupational epidemiology is the job exposure matrix (JEM). A JEM can either be designed for a specific study, or be ‘generic’ for use in a variety of studies [58]. In general, JEMs include an estimate of the prevalence of exposure (or probability of exposure in any job or job/industry combination), as well as some marker of intensity of exposure.

There have been general JEMs created to evaluate exposure to a wide variety of agents (most notably FINJEM, which includes occupational sun exposure as an exposure) [59]. Study-specific JEMs for UVR have also been developed in European settings [60, 61]. However, these studies relied on broad industrial categories as the unit of measurement, and sun exposure is much more driven by job title. The jobs that are considered typically ‘outdoor jobs’ likely do not vary much between countries, so a generic JEM for outdoor work would be a useful instrument for exposure assessment in any country. Of course, ambient levels of UVR do vary by country (quite drastically), so the concept of low, medium and high exposure will mean very different things if one is working in Australia versus Canada. Ambient UVR levels available at the surface of the earth can be estimated from satellite instruments. The Total Ozone Mapping Spectrometer (TOMS) from NASA was mounted on many spacecraft and collected UVR data for the earth’s surface from 1996 – 2005 [55]. Global UVR data is now freely available from the Global UV (glUV) project, which synthesizes UV-B radiation data from NASA’s AURA satellite, and in particular from the Ozone Monitoring Instrument (OMI) [62]. Several ecological studies of solar UVR have been completed using satellite data from these datasets [63-65], and they have a distinct advantage of being able to assume a potential exposure level for individuals based on their address.
1.5.3 The impact of gender on UVR exposure and cancer risk

The reasons for gender differences in UVR exposure and skin cancer outcomes are multifaceted, but gender is the demographic factor that is most often and most strongly associated with sun protective behaviour [66]. This makes it a vital consideration in any skin cancer prevention program, and indeed a review of the literature shows that it seems highly important that prevention programs be based on gender-specific behavioural data [66].

In Canada, young women practice sun protection behaviors more than young men (58% versus 42%), however young women are more likely to try to get a tan from the sun, and also to use tanning beds [41]. Overall incidence rates for melanoma in Canada are higher among men than women (14.0 / 100,000 in men; 12.4 / 100,000 in women); however the rates are higher for women aged 15-49 years. For unknown reasons, melanoma occurs more often in women in Europe, but the opposite is observed in the US, Australia and Canada [67].

Men tend to have higher cumulative exposure to solar UVR, and this is at least partially explained by their higher probability of occupational exposure; approximately three-quarters of outdoor workers in Canada are male [40]. Women are more likely to use sunscreen (and use it correctly) both on the job and in leisure time, and are also more likely to seek shade. Contrarily, women are more likely to have a positive view of sunbathing and sunbed use, especially in their youth [66]. There is some evidence that women tend to view sun protection more positively because of beauty norms surrounding aging [66], and indeed some interventions in young women have emphasized beauty standards ahead of skin cancer prevention.

Sun protection behaviour may differ between jobs in a way that reflects the culture of the workplace. For example, females are more prevalent in recreational and lifeguarding industries, and these outdoor occupations also tend to have better sun protection practices among workers [3]. The sun-safety habits of workers are very likely influenced by gender norms, and within other contexts, women have been found to undertake more preventive health behaviours, perhaps due to higher perceived vulnerability or perception of the severity of risk [68]. Sun exposure may also have sex-specific effects, beyond the more gender-focused ones. Some evidence exists to suggest that UVR may protect against breast and prostate cancer (along with the more widely accepted colorectal cancer) as two sex-based cancers [69].

1.6 Objectives and rationale

The relationships between ultraviolet radiation exposure and skin and prostate cancers are complex. Exposure assessment for solar UVR has focused mainly on questionnaire data, and very little on objective measures. For prostate cancer, the link with solar UVR remains tenuous, with many calls for further research, in particular among highly-exposed, male-dominated outdoor workers. The purpose of this PhD thesis is to address these knowledge gaps in exposure assessment for solar ultraviolet radiation in outdoor workers. The particular knowledge gaps to be addressed are outlined in more detail, as follows:
1. Lack of a standard job exposure matrix (JEM) for outdoor work

A general job exposure matrix (JEM) for outdoor work has not been developed beyond use for individual studies, and in particular, one has not been developed in a detailed North American industry and occupation coding system. Generic tools are required in epidemiology as they are inexpensive and feasible for use with a large number of workers. The objective of Chapter 2 is to develop a job exposure matrix for population-level UVR exposure assessment in Canada, and to examine the use of satellite measures of solar UV-B at the earth’s surface as a weighting tool for location in this JEM.

2. Solar UVR exposure is mediated by protective behaviours and practices, but information on what determines the protective behaviours and practices used by outdoor workers is not widely available

Exposure to solar UVR is often thought of as a personal problem, even when the exposure takes place in the context of a person’s job. Understanding what determines workplace sun protection behaviours could help identify key practices or policies to encourage better protective practices while at work, particularly among men (who are reported to practice less protective behaviours). The objective of Chapter 3 is to examine the determinants of sun protective behaviours in a sample of male outdoor workers in Canada.

3. No objective measures of solar UVR exposure exist for Canadian workers. How big of a problem is solar UVR in Canada’s outdoor workers?

Though sun exposure is the main cause of skin cancer, and that skin cancer incidence is increasing in the Western world, objective measures of typical Standard Erythemal Doses (SED) experienced by Canada’s outdoor workers is not available. The objective of Chapter 4 is to characterize the summertime UVR exposure levels in an outdoor worker population in British Columbia, Canada using direct dosimetry measurement.

4. Some evidence exists that solar UVR exposure might reduce the risk of prostate cancer, but few studies have been done in outdoor workers.

There has been a great deal of research on the experimental validity of the idea that solar UVR exposure can reduce the risk of prostate cancer and increase the chances of survival, but the epidemiologic evidence is more equivocal. The objective of Chapter 5 is to examine the relationship between UVR exposure on the job (using the satellite-enhanced JEM from Chapter 2) and subsequent risk of prostate cancer to contribute to the epidemiologic literature surrounding solar UVR exposure and prostate cancer.
1.7 Context of the thesis: The Outdoor Workers Project and the National Enhanced Cancer Surveillance System

1.7.1 The Outdoor Workers Project

The Outdoor Workers Project (OWP) was a field-based, cross-sectional study designed to assess the quantitative levels of solar UVR exposure in an outdoor worker population in the Canadian province of British Columbia (BC), with the highest percentage of outdoor workers in Canada. In addition, the study sought to examine how outdoor workers protect themselves from the harmful effects of the sun, and whether or not these practices were linked to risk factors for developing skin cancer. The OWP was developed by Cheryl Peters and funded by the Canadian Dermatology Foundation in June 2012. Pilot testing began in February 2013, and the field monitoring occurred between June and September of 2013. This study was designed and carried out for the purposes of this thesis and was approved by the University of British Columbia’s Behavioural Research Ethics Board (certificate H11-01272).

The target population for the OWP was industrial construction workers (e.g. heavy equipment operators, ironworkers, road builders), but this was amended after the start of the study to also include horticultural workers to increase the size of the study. Worksites were selected via their trade unions, in particular as identified by the British Columbia and Yukon Territory Building and Construction Trades Council (BCYT-BCTC). The BCYT-BCTC is an umbrella organization for 15 unions representing approximately 40,000 workers in BC. Worksites were also recruited by word-of-mouth. The exposure assessment methods used in the Outdoor Workers Project are described in greater detail in Chapters 3 and 4, but a brief overview is provided here.

1.7.1.1 Data collection

After providing written consent to participate, workers took part in three data collection activities; 1) completing a questionnaire; 2) wearing a UVR dosimetry badge for 5 consecutive work days (where possible); and 3) completing a task-related diary hourly with a pre-set list of tasks and positions, and information on shading provided during tasks.

The questionnaire was adapted from a standardized set of questions on sun protection behaviours or practices, and skin cancer risk factors [70]; a copy of the full questionnaire used in the study is included in Appendix I. Modifications included questions on the current job and general tasks performed (to allow for task-based determinants of exposure), and susceptibility factors that fall into four categories, namely skin type (i.e. pigmentation, freckling, hair/eye colour), demographic (age, sex, family history), past exposure (childhood sunburns), and tanning behaviours. Pilot testing of the questionnaire was also carried out to ensure ease of comprehension with minor edits to wording. A copy of the task diaries used during the study is provided in Appendix II. It was designed for convenience for the workers by using pictures where possible.
The UV dosimetry badges were battery-powered and featured data-logging as often as every 8 seconds, allowing for short-term and full-shift exposures to be quantified [71]. The badges were calibrated at the beginning and end of the sampling season. Calibration was performed using a Robertson-Berger UVB-1 Broadband Pyranometer, owned by Environment Canada and located in the city of Richmond, British Columbia (in close proximity to where sampling took place) [72]. Dosimeters were programmed to sample from 8AM to 5PM each day, once per minute. Workers wore the badges for 5 consecutive work days, where possible.

1.7.2 The National Enhanced Cancer Surveillance System

The second data source used for this thesis was the National Enhanced Cancer Surveillance System (NECSS), which was a large initiative developed in the 1990s as a collaboration between Health Canada and the Provincial Cancer Registries [73]. The details of this study have been published elsewhere [74-76], but in brief, it consists of several components relevant to environmental quality, epidemiology and communications. For the purposes of this thesis, the NECSS refers to the case-control dataset of newly-diagnosed, histologically-confirmed cancer cases (in this case, prostate) and population controls, along with detailed risk factor information. Risk factor information collected included lifetime residential and occupational history, smoking history, diet, and physical activity information.

Cases were identified early in the cancer registration process so that subjects would be less likely to be lost to severe illness or death. The questionnaire response rate for the NECSS was 69% for both cases and controls. A previous analysis of this dataset to create a predictive model for prostate cancer risk factors was published by Villeneuve et al. [34]. The purpose of using it for this thesis was to examine the hypothesis that higher cumulative occupational exposure to solar UVR leads to lower risk of prostate cancer. A copy of the data request/proposal to use the NECSS dataset is provided in Appendix C.

More details of how this exposure assessment was carried out are provided in Chapter 5, but in brief: a job exposure matrix for outdoor work (SUNJEM) was created using job titles identified as likely to occur outdoors, coupled with estimates of time spent outside per day to construct categories of low, moderate and high exposure. This SUNJEM was used on its own to assess the risk of prostate cancer, but also was augmented with ambient solar UVR data for each outdoor job held by a study subject throughout their working lives.
Chapter 2: Estimating population-level exposure to occupational solar ultraviolet radiation (UVR) in Canada

2.1 Introduction

2.1.1 Occupational skin cancer

Approximately one third of newly diagnosed cancers in Canada in 2014 were skin cancer (6,500 of which were melanoma, and a further 76,100 of which were basal and squamous cell carcinomas, collectively known as non-melanoma skin cancer [NMSC]) [1]. Despite the fact that they are largely preventable (by limiting ultraviolet radiation [UVR] exposure) the incidence of skin cancer is increasing in Canada [25].

Outdoor workers (people who spend a majority of their working time outdoors, e.g. construction workers, farmers, postal workers) are a group at particular risk of high UVR exposure [3]. Elevated rates of NMSC are seen in outdoor workers compared to indoor workers, and the risk is increased among those with the highest exposure [77].

Occupational epidemiologic research (and cancer prevention efforts) requires information on the occurrence of exposure, especially how many people are exposed and where (occupation and industry), but this information is rarely available [78]. Exposure surveillance data of this type has many potential uses in the primary prevention of workplace cancers, including priority setting for prevention activities, targeting of high-risk groups (either for monitoring or exposure reduction strategies or both), education for the public and policy makers, the monitoring of trends, and the prediction of future disease for resource allocation decisions [79].

2.1.2 Job-exposure matrices

Occupational exposure surveillance data in the form of exposure estimates can also be used to create a standard tool called a job exposure matrix (JEM). The concept of JEMs was created in response to a need for increased specificity and efficiency when undertaking occupational epidemiologic studies. One of the first JEMs (though it was actually called a ‘linkage system’ at the time) was developed by Hoar-Zahm and colleagues because most studies of occupational exposures prior to 1980 used job title and industry (or potentially work task) as markers of exposure themselves, and related cancer rates (for example) to working in that industry or doing that task, rather than to specific exposures [80]. This had the effect of potentially obscuring any elevated disease rates of a subgroup of workers in that industry. In addition, similar work tasks could be performed in any number of industries, but only harmful in a subset [80]. JEMs offer a methodological tool to use existing information to assign individual-level exposures.
Job-exposure matrices can either be designed for a specific study, or be ‘generic’ (for use in any study in a particular country or region) [58]. These matrices (in general) include exposure metrics (based on expert judgment, measured data, or sometimes both) linked to particular industries and occupations [81-83]. They may also include a time component, as is the case with the Finnish generic JEM (FINJEM), for example [59]. The exposure metrics noted in the cells of the matrix indicate the presence and intensity, and/or prevalence of exposure in a particular industry and occupation [83]. The design of JEMs can be very flexible and can range from the very simple to the very complex, with dimensions such as plant, department, machine type, work process, or the presence of exposure controls included in the structure [84].

The process of using a JEM groups all workers in a given combination of work factors (dimensions of the JEM) and assigns the same exposure metric. This can seem problematic, as there is often large variability in measurements within the same worker, between workers in the same job, and between different jobs. These differences stem from (among other factors) changing work tasks, processes, and locations over time [85].

The error involved when a mean exposure for a group is assigned instead of an individual’s measured exposure is called a Berkson error (differentiated from classical measurement error) [86]. Grouping schemes (such as are used in JEMs), or when a group mean is used rather than the individual measures, actually make the most of the Berkson error, since attenuation (biasing to the null result) of the exposure-response relationship is less than when individual measures are used [87]. Attenuation of the exposure-response relationship is also reduced when the between-group variability is higher than the within-group variability, and this is more likely to occur when we consider similar groups of workers together in terms of their exposure metric [85, 87, 88].

In addition to the statistical benefits of using grouped exposure metrics, JEMs are a less costly, more transparent and reproducible tool than the alternative, which is a case-by-case expert assessment or individual exposure monitoring [89]. To date, a generic JEM for occupational UVR exposure has not been made available for broad use, and not specifically for the Canadian context.

### 2.1.3 CAREX Canada

CAREX Canada is a national carcinogen exposure surveillance project that used methods adapted from the CAREX European project of the same name developed by the Finnish Institute of Occupational Health [78]. The goals of CAREX Canada were: 1) to develop estimates of the numbers of workers exposed to high priority carcinogens; and 2) to develop estimates of the levels of exposure to these carcinogens in Canada, where data allows. During the CAREX process, proportions exposed by industry and occupation (as well as exposure levels assigned) are coded by one hygienist, reviewed by a second, and finalized by consensus with a third where discrepancies arose.
For this study, the objective was to construct a job exposure matrix (JEM) for application in epidemiologic studies of UVR exposure using estimates of the prevalence and level of exposure to the sun.

2.2 Methods

2.2.1 Prevalence and level of exposure to solar radiation

Exposure to solar UVR was defined as having a job that requires working outdoors for at least 2 hours per day. It did not include recreational sun-bathing or occupational exposure to artificial sources of UVR (e.g. tanning beds, welding arcs). In the original CAREX project done in the European Union, jobs were counted as exposed if workers were expected to be outside ≥75% of the workday. This definition was used in the present study for Canadian estimates to define a ‘high exposure’ category. Industry was classified by North American Industry Classification System (NAICS, 2002) and occupation by the National Occupational Classification for Statistics (NOC-S, 2006) [90].

In order to identify jobs in the high exposure category, the occupational skin cancer prevention workbook developed by Cancer Council Australia’s SunSmart program was used to identify ‘typical’ outdoor jobs [91]. This category includes such jobs as gardeners and roofers, where all workers are expected to have relatively high exposure to UVR. In addition, an indicator variable noting level of confidence in the estimate was also included for all job and industry combinations. Published studies that flagged jobs as exposed to solar UVR were consulted to confirm the selection of job titles [77, 92, 93].

In order to create other exposure categories that were relevant to the Canadian context, the focus was on occupation first, and industry second. To classify occupations with respect to UVR exposure, two career-selection websites were consulted. These resources described tasks by job title and included information on outdoor work and expected amount of time spent outdoors [94, 95]. This allowed the creation of an unexposed category (i.e. almost never exposed, such as office managers), a low-exposed category (i.e. intermittent exposure, or exposure with protection of some kind, such as a truck cab), as well as 2 moderate exposure categories. Moderate exposure categories were divided into two types where workers in the same job fall on the continuum between ‘always’ and ‘never’ exposed: 1) all workers in that job were similar and perform similar, but mixed indoor and outdoor tasks; and 2) different workers in the job had different time spent indoors and outdoors. For moderate exposure Group 1, the proportion of workers exposed to solar UVR was assigned to reflect an approximate weighting for the time spent outdoors. An example of this job type is a construction inspector; while much of their work is indoors, site inspections may take up a significant proportion of the day and could involve solar UVR exposure. For moderate exposure Group 2, industry information was reviewed to assign the proportion of workers exposed. For example, the occupation ‘Tour and Travel Guides’ includes people who work outdoors all day (i.e. providing walking tours in a city) and also those who work indoors all day (people offering tours of historic buildings).
Next, in situations where exposure is largely driven by industry rather than occupation, jobs were selectively added in as ‘exposed’ to UVR in those industries. This usually occurred in the farming and construction industries where jobs that may normally take place inside are located outside. For example, the job code H144 (Painters and Decorators, in the NOC-S 2006 classification) mostly includes indoor workers with a negligible number of outdoor workers in the whole workforce. Within the construction industry however, a substantial proportion of this job would be exterior building painters, and so a proportion was flagged as exposed in this industry only.

Once all job and industry intersections were evaluated for the proportion of outdoor workers exposed to UVR, these proportions were applied to the 2006 Canadian Census of Population to obtain estimates of the number of people exposed to UVR on the job by industry, occupation, and sex [96].

2.2.2 Creation of SUNJEM job exposure matrices for UVR exposure

The process of developing prevalence estimates in the context of the CAREX Canada project inherently involved the creation of matrices (with industry on one axis and occupation on the other) of proportions of people exposed. For the development of a generic JEM for UVR exposure, job-industry intersections were automatically flagged as exposed if the proportion exposed in the CAREX Canada prevalence matrix was ≥75%. Exposure levels were assigned a numeric value of 1, 2 or 3 (corresponding to low, moderate, and high exposure). For intersections where less than 75% of workers were flagged as exposed, a ‘review’ flag signals that exposure should be investigated further based on additional text or contextual details often available in population-based datasets (for example, information that allows better allocation of outdoor work) [97]. As a general rule, if more than 25% (or 2 hours for a typical 8-hour shift) of the workday could be expected to be outdoors, then the job was assumed exposed [43].

The generic JEM only accounts for exposure level based on time assumed to be spent outdoors with no consideration of location. This is important because location influences the available ambient UVR, and thus exposure level among those working outdoors. As an enhancement, the gJUV (Global UV-B radiation dataset for macroecological studies, data available from 2004 and forward in time) project dataset of UVR irradiance (the erythemally weighted UV energy incident on the earth’s surface, in Joules per square meter) can be used to weight an outdoor worker’s exposure based on where they lived at the time they had an outdoor job. The gJUV uses UV-B data from the Ozone Monitoring Instrument (OMI) onboard the NASA EOS Aura spacecraft [62]. These data are available freely online. This component is designed for use in epidemiologic studies where an individual’s home or work address may be available in addition to their job and industry. Readers are directed to Chapter 5 of this dissertation for a further description of this location-based enhancement to the JEM, which should be considered for use as a valuable tool in future epidemiological research of occupational solar UVR exposure (it is available for any location).
2.3 Results

Overall, approximately 1.5 million Canadians (82% males) were estimated to be exposed to solar UV on the job for at least 2 hours per day; this represents 8.8% of the Canadian working population. Notably, 61% (896,000) of those exposed fell in the high-exposure category, which denotes workers who are outside ≥75% of the time. The proportion of workers exposed within a job or a job/industry combination ranged from 2 to 100% of workers per category.

The largest number of workers exposed, the percentage of workers exposed in that job, and the exposure category (high, moderate, low) are shown in Table 2.1. The job groups most often represented across these different exposure categories were farmers and landcsapers, and construction trades helpers. It should be noted that these numbers were driven by the proportion of workers exposed in a job, but also the size of the occupation in Canada.

These methods also permitted the examination of exposure by industry. The most important broad categories (with respect to total number of workers exposed) were construction, agriculture, forestry, fishing and hunting, and services to buildings. Exposure by industry at a more detailed level is shown in Table 2.2.

Table 2.1 Prevalence of exposure to solar ultraviolet radiation in Canada by occupation

<table>
<thead>
<tr>
<th>Occupation</th>
<th>Total population exposed (n)</th>
<th>% exposed</th>
<th>Exposure category*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmers and farm managers</td>
<td>149,000</td>
<td>75</td>
<td>High</td>
</tr>
<tr>
<td>Construction trades helpers and labourers</td>
<td>124,000</td>
<td>75</td>
<td>High</td>
</tr>
<tr>
<td>Landscaping and grounds maintenance labourers</td>
<td>114,000</td>
<td>100</td>
<td>High</td>
</tr>
<tr>
<td>General farm workers</td>
<td>84,000</td>
<td>80</td>
<td>High</td>
</tr>
<tr>
<td>Heavy equipment operators (except crane)</td>
<td>83,000</td>
<td>100</td>
<td>Moderate</td>
</tr>
<tr>
<td>Truck drivers</td>
<td>61,000</td>
<td>20</td>
<td>Low</td>
</tr>
<tr>
<td>Carpenters</td>
<td>53,000</td>
<td>40</td>
<td>Moderate</td>
</tr>
<tr>
<td>Delivery and courier service drivers</td>
<td>51,000</td>
<td>50</td>
<td>Low</td>
</tr>
<tr>
<td>Public works and maintenance labourers</td>
<td>33,000</td>
<td>100</td>
<td>Moderate</td>
</tr>
<tr>
<td>Couriers, messengers and door-to-door distributors</td>
<td>30,000</td>
<td>100</td>
<td>Moderate</td>
</tr>
<tr>
<td>Letter carriers</td>
<td>29,000</td>
<td>100</td>
<td>High</td>
</tr>
<tr>
<td>Fishing vessel skippers and fishermen/women</td>
<td>28,000</td>
<td>100</td>
<td>High</td>
</tr>
<tr>
<td>Heavy-duty equipment mechanics</td>
<td>27,000</td>
<td>70</td>
<td>Moderate</td>
</tr>
<tr>
<td>Roofers and shinglers</td>
<td>22,000</td>
<td>100</td>
<td>High</td>
</tr>
<tr>
<td>Nursery and greenhouse workers</td>
<td>22,000</td>
<td>100</td>
<td>High</td>
</tr>
<tr>
<td>Bricklayers</td>
<td>19,000</td>
<td>100</td>
<td>High</td>
</tr>
</tbody>
</table>

*High exposure: job expected to be outdoors ≥75% of the work day
Moderate exposure: EITHER 1) job has a mix of indoor and outdoor workers (i.e. tour guides); OR 2) all workers in the job have between 2 and 6 hours of outdoor work per day expected, on average (mixed exposure).
Low exposure: Exposure is intermittent or there is inherent protection (i.e. by a truck cab).
Table 2.2 Prevalence of exposure to solar ultraviolet radiation in Canada by industry

<table>
<thead>
<tr>
<th>Industry</th>
<th>Total population exposed (n)</th>
<th>% of industry exposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farms</td>
<td>264,000</td>
<td>68.6</td>
</tr>
<tr>
<td>Residential building construction</td>
<td>108,000</td>
<td>36.0</td>
</tr>
<tr>
<td>Services to buildings and dwellings</td>
<td>83,000</td>
<td>31.7</td>
</tr>
<tr>
<td>Foundation, structure, and building exterior contractors</td>
<td>68,000</td>
<td>55.5</td>
</tr>
<tr>
<td>Local, municipal and regional public administration</td>
<td>60,000</td>
<td>20.8</td>
</tr>
<tr>
<td>Other amusement and recreation industries</td>
<td>45,000</td>
<td>29.6</td>
</tr>
<tr>
<td>Other specialty trade contractors</td>
<td>40,000</td>
<td>50.8</td>
</tr>
<tr>
<td>Support activities for mining and oil and gas extraction</td>
<td>39,000</td>
<td>37.4</td>
</tr>
<tr>
<td>Fishing</td>
<td>37,000</td>
<td>89.0</td>
</tr>
<tr>
<td>Logging</td>
<td>36,000</td>
<td>62.9</td>
</tr>
</tbody>
</table>

Figure 2.1 Percentage of the working population exposed to solar ultraviolet radiation at work, by province/territory*

The provinces with the largest population had more people exposed but the proportion of exposed workers was dependent on the occupations and industries represented in the provincial workforce. This is illustrated in Figure 2.1. While the province of Ontario had the largest number of solar UVR-exposed workers (450,000, data not shown), relatively few Ontario workers were exposed (6.9%) as a proportion of the entire workforce. In contrast, 17.3% of the Prince Edward Island workforce was exposed (n=13,000).

The JEM created directly from CAREX coding structures for occupational sun exposure contained 523 data lines, one for each 4-digit job in the NOC-S 2006 coding structure. Of these jobs, 51 were flagged as exposed (10% of jobs), and a further 79 were flagged for secondary review. As an example, for code F153 (Sports officials and referees), where 20% were flagged as exposed for the CAREX prevalence estimate, the secondary flag instructs the analyst to change the flag to exposed and the exposure level to 2 (moderate) if there is evidence of the official working in an outdoor venue. If this information were not available, this intersection would remain un-flagged for exposure (since less than 75% of workers were assumed exposed).

Data from the glUV project linked to residential histories in Canada (with selected locations from the dataset analyzed in Chapter 5) was used to produce Figure 2.2. Values for the daily average Standard Erythemal Dose (SED) for both the highest exposure month of the year by location (typically June), and the annual daily average SED are depicted. Overall, exposure values were variable, but not extremely so (average SEDs in the highest exposure month ranged from 27.4 in Inuvik, Northwest Territories to 49.0 in Milk River, Alberta; yearly averages ranged from 11.0 in Keno Hill, Yukon Territory to 24.0 in Windsor, Ontario).

2.4 Discussion

The results showed that occupational exposure to UVR in Canada is common, with approximately 1.5 million workers estimated as exposed, and 896,000 of these in the highest category of exposure (5.3% of Canadian workers). In the Second National Sun Survey in Canada (NSS2), workers that ‘reported having a job that required them to work outdoors during the summer months of June, July and/or August of 2006’, resulted in an estimated 5.9 million Canadians as potentially exposed [40]. The estimates presented here are lower, but there are two plausible reasons for this, stemming from differences in definitions of outdoor work in the NSS2. Firstly, there was no definition of what qualifies as ‘working outdoors’ in the NSS2, and respondents could have answered ‘yes’ based on minimal time spent outside. In addition, participants were asked about a specific calendar period. This could have led to higher levels of exposed where a specific project required outdoor work for a short time. In the current study, the detailed review of several data sources was focused on increased specificity of exposure classification. Our prevalence of exposure was lower than an Australian study of the prevalence of occupational sun exposure (22% of all survey respondents were exposed), but this is very likely to be due to climatic and weather differences [98]. In addition, our estimates were similar to those in Great Britain, a country with similar exposure to that of Canada with respect to latitude. There, it was estimated that 6.8% of workers were exposed to solar UVR at work [99].
Our estimate ranged from 5.3 – 8.8%, with the lower-end representing those at high risk, and the upper-end representing all workers at risk of exposure.

Figure 2.2 Typical values for total available Standard Erythemal Dose (SED) across Canada (daily average in highest exposure month, daily annual average)

The creation of a JEM (either for generic use or where work or home location of workers is available, location mapping capability) provides a new tool for population-based studies of the health outcomes associated with solar UVR exposure (e.g. various skin cancers, prostate cancer, vitamin D levels). Exposure assessment for occupational solar UVR has been slow to accumulate any quantitative data (personal dosimetry) on outdoor workers’ exposure levels, which has hampered efforts to create JEMs of this nature before [54]. This effort provides novel JEMs based on expected time spend outdoors (with or without location information) in the absence of measured exposures that are much more often available for other traditional occupational hazards. The satellite data enhancement could prove a useful addition, especially if subjects in a study are spread out over a large geographic area that is more prone to have variability in the available ultraviolet radiation (UVR).

Recent criticisms of the JEM method for exposure assessment have been made, instead calling for the use of Bayesian or semi-Bayesian methodologies to address the (sometimes unpredictable) biases caused by the use of JEMs [100]. However, it has been shown that the three conditions in which group-based exposure assessments are less likely to perform well include 1) where there is large variation between workers within a group; 2) when the
prevalence of disease is low; or 3) when a large increase in risk occurs for a 1-unit increase in exposure [101]. The JEMs created in this study are not particularly at risk for any of these conditions. Care was taken to err on the side of specificity by including mostly jobs where 75% of workers are likely to be exposed, skin and prostate cancers are common outcomes in men, and there are not dramatic increases in risk, at least for skin cancer, seen in occupational studies when comparing ‘exposed’ versus ‘unexposed’ as an exposure metric [102].

There were several limitations to this study that should be noted. First, solar UVR exposure in Canada is not directly comparable to exposure in Australia, and Australian guidelines for identifying those at risk of exposure were used. However, relatively speaking, jobs in Australia are not different from jobs in Canada with respect to the potential for time spent doing outdoor work (i.e. a gardener is an outdoor worker whether they are in Canada or Australia). Therefore, exposure levels should be qualitatively similar, though absolute values are higher in Australia.

Better estimation of exposure in the context of an epidemiological study can theoretically be achieved when the JEM is applied with location-specific information included (i.e. when location information is available for study subjects, allowing a correction to be applied for available UVR). This is due largely to the effect of latitude, which is particularly important for northern Canada. We can see in the north (Figure 2.2) that a relatively high proportion of the workforce was classified as exposed due to outdoor work in the primary industries (a large part of the northern labour market). The level of exposure to solar UVR decreases away from the equator, so the risk of skin cancer is expected to be lower in the north. However, even if location information is not available and the generic JEM were to be used in a study, most Canadians (about ¾) live within 160 kilometers of the Canada-US border [103], making latitude a less important modifier. There is also the potential that the exposure metric used (working outdoors) differs by province, and this was more likely to occur where weather patterns were markedly different. However, mean UV Index values for North America have been mapped and matched quite well with latitude (particularly in summer) [10], which diminishes the impact of east-west variability (differences by province). In addition, the relative levels of exposure will hold true regardless of province. However, any residual concern about location-specific errors in the generic JEM could be further alleviated by adjusting the exposure metrics based on the location-corrected JEM.

The seasonality of outdoor work in Canada was incorporated into the assigning of exposure proportions, but over-estimation of outdoor work may have occurred where exposure occurs mostly in summer. The degree of uncertainty related to seasonality was incorporated into the estimates by flagging jobs in a ‘high exposure’ category where there was more certainty of year-round exposure and by providing a range of the number of workers exposed. In addition, most outdoor work in the Canadian winter involves exposures below a UV Index level of 3 (low risk), except for those people who work in ski resorts (higher exposure from snow reflection combined with high elevation) [10].

In summary, occupational solar UVR exposure occurs on a large scale in Canada. Estimates of the prevalence of exposure to solar UVR are important to facilitate targeted prevention
strategies in the workplace, in addition to population-level studies on the occupational burden of skin cancer. The extension of these UVR exposure prevalence estimates into a more broadly applicable job exposure matrix provided a data source for assessing the risk of prostate cancer in outdoor workers for another epidemiologic study in this PhD dissertation (Chapter 5).
Chapter 3: Sun protection behaviours among outdoor workers in Vancouver, Canada

3.1 Introduction

Non-melanoma skin cancers (NMSC, including squamous cell carcinoma (SCC) and basal cell carcinoma (BCC)) are the most common malignancies worldwide and in Canada [104]. In 2014, over 76,000 new cases of NMSC were diagnosed in Canadians, and due to inconsistent reporting practices, this number is assumed to be an underestimate [1]. The main risk factor for NMSC is excessive exposure to solar ultraviolet radiation (UVR), and of particular concern as an occupational cancer risk for people who work outdoors. Ultraviolet radiation exposure is also causally-related to cutaneous melanoma, cataract and possibly ocular melanoma [105].

National and international guidelines on skin cancer prevention in the general population tend to focus broadly on three lines of prevention in priority order: 1) keeping people out of the sun; 2) covering up with clothing and hats; and 3) wearing sunscreen [106, 107]. While it stands to reason that these principles could be applied under a regulatory framework to occupational settings in North American jurisdictions, this is rarely done. Instead, prevention is either self-regulated (mostly informally) [108] by industry or tackled by the use of voluntary guidelines and toolkits [109], if addressed at all.

Occupational settings represent a particular challenge for skin cancer prevention. A good example is provided by an American study of dairy farmers [110]. Farmers in this study reported knowledge about skin cancer, agreed that it was a serious disease, believed that they were more susceptible than the general population, and believed in the usefulness of sun protection. However, most did not protect themselves from the sun, and nearly half thought that people look better with a tan [110]. Perhaps even more intriguing, in a study of workers who had already been treated for skin cancer (NMSC), researchers found no difference in sun protection behaviors between those who worked indoors versus those who worked outdoors, even though outdoor workers’ exposure was much higher, including in their leisure time [111]. The most common reason for not wearing sun protection reported was “didn’t get around to putting it on.”

A recent review of skin cancer prevention strategies in outdoor workers revealed wide variation in the use of regular protective equipment by workers across studies [112]. Even among one occupational group (farmers, for this example), the proportion of workers reporting ‘often or always’ wearing a wide-brimmed hat at work ranged from 10 [113] to 39% [114]. The most frequent protection method used by workers was sunglasses, though this may have been to prevent glare rather than for cancer prevention purposes [112, 115].

Canadian studies on sun protection behaviours in outdoor workers are rare; only three were identified. Two of the Canadian studies were from the Canadian National Sun Survey (NSS in
1996 and NSS2 in 2006), aimed at understanding sun exposure and protection in the general Canadian population (including outdoor workers) [40, 43]. In the NSS2 study, self-identified outdoor workers reported covering their heads as the most frequently used protective behaviour (58% reporting often/always) and sunscreen use as the least frequently used behaviour (29% reporting often/always). However, there were significant differences between men and women on the most and least frequently reported behaviours: 60% of men reported covering their heads compared to 44% of women, while 20% of men reported frequent sunscreen use compared to 56% of women [40]. Protective clothing and sunglasses were used often or always by approximately half of respondents in the NSS2. Results were very similar in the original NSS survey, with sunscreen and sun avoidance the least commonly used sun protection behaviours, and protective clothing and hat use the most commonly used techniques [43]. The third Canadian study presented the results of a pilot survey of 207 farmers in Ontario, completed in 1998 [116]. This study found less frequent use of sun protection that the larger NSS surveys, with only 35% of farmers routinely wearing a hat, and just 22% wearing long-sleeved shirts. No other Canadian information on protective behaviours in particular industries or occupations (including high exposure groups such as construction) was available (the NSS surveys did not collect job title information).

3.1.1 Gender differences in behaviours and risks

Men tend to have higher cumulative exposure to solar UVR, which may be partly explained by their higher occupational exposure; approximately three-quarters of outdoor workers in Canada are male [40]. Men also experience more NMSC diagnoses than women (approximately 55% of the total diagnoses in Canada), and they are also more likely than women to die of melanoma [1]. This difference in prevalence may relate to occupational sun exposure, but may also be due to differences in sun protection and biological differences in human skin by sex (that could affect inherent susceptibility) [117, 118].

Women are more likely than men to use sunscreen (and use it correctly) both on the job and in leisure time, and are also more likely to seek shade. Sun protection behaviour may differ between jobs in a way that reflects the culture of the workplace. For example, women are more prevalent in recreational and lifeguarding industries, and these outdoor occupations also tend to have better sun protection practices for workers [3]. Men are more prevalent in industries such as farming, forestry and construction that have very high exposure to the sun and also reflect a culture where the use of sun protection behaviours may not be very strong [68]. The sun-safety habits of workers are very likely influenced by gender norms. Women have been found to undertake more preventive health behaviours, perhaps due to higher perceived vulnerability or perception of the severity of risk [68]. Therefore, a focus on men’s health in the context of skin cancer prevention is useful for identifying areas for improved exposure reduction strategies. In this study, the focus was to address male-dominated industries with large outdoor workforces (in this case, construction).
3.1.2 Context of this study: The Outdoor Workers Project

The purpose of the Outdoor Workers Project (OWP) was to 1) characterize the solar ultraviolet radiation (UVR) exposure levels in outdoor construction workers, a male-dominated workforce, in and around Vancouver, British Columbia, Canada; and 2) to understand what factors determine UVR exposure levels in these workers. Data on sun protection behaviours were collected via a questionnaire (along with demographic, work history and task information), and these data were used in the present study to answer the following research questions:

1) How prevalent are sun protection behaviours while at work among outdoor construction workers in British Columbia; and

2) What are the determinants of the protective behaviours identified in Question 1?

This information is useful for targeting where occupational skin cancer prevention policies or guidelines could be helpful in reducing occupational sun exposure in the Canadian construction worker population, and in particular this group allows us to examine men’s health behaviours (as a high risk group).

3.2 Methods

3.2.1 Study design

The Outdoor Workers Project (OWP) was a cross-sectional UVR exposure assessment study that took place in the summer of 2013 (data collection from July to September) in the Vancouver, British Columbia area. As part of the OWP, workers wore an electronic UVR dosimeter badge for 5 working days, and filled out an activity diary once per hour (see Chapter 4 for exposure results). Workers also filled out a questionnaire that included questions on demographics, skin cancer risk factors, job characteristics, and sun protection behaviours and habits undertaken while at work as well as in leisure time. The questionnaire was the data collection tool used for the current analysis.

3.2.2 Study sample (inclusion/exclusion, recruitment methods)

Participants in the Outdoor Workers Project (OWP) were recruited via building trade unions and by approaching companies with outdoor operations via their health and safety staff. Several workers also learned about the study via word-of-mouth; some of these workers were not in the construction industry, but were still mostly men working in male-dominated workplaces (horticulture/landscaping and wildlife protection), so they were also invited to participate. Worksites needed to be amenable to having at least 2 site visits by the study coordinator (on the first and last days of sampling), and workers were provided with a study information sheet prior to their decision to participate. On the first morning of the scheduled sampling work week, eligible workers were provided with a study invitation letter and a short training session on the components of the questionnaire and instructions for using the UVR dosimeter badges.
Eligibility was met by those workers who were 18 years of age or older, and who spent at least part of an average workday outdoors. Although ideally the worker would have expected to work five days during their sampling week, those with less than five days scheduled were also invited to participate (those who worked more than 5 days were also invited to include those additional sampling days as well). All participating workers provided informed consent. The study protocol was approved by the University of British Columbia Behavioural Research Ethics Board (certificate H11-01272).

3.2.3 Data collection and analytic variables

Data collection for the present study involved the use of a self-completed detailed questionnaire; a full description of the UVR exposure data collection methods and procedures is provided in Chapter 4. The questions used were selected from a standardized core set of questions developed for measuring sun protection behaviours in a wide variety of populations (workers included) [70]. A pilot version of the questionnaire was pre-tested on a subset of 5 outdoor workers, and some modifications were made to the final version based on their feedback (including increased clarity on skin type and hair colour descriptions).

Risk factor and demographic variables included age, sex, number of hours spent outdoors between 10am and 4pm on an average workday and an average leisure day (range from 1 to 6), spending time in the sun to get a tan (often/always or sometimes/rarely/never), reporting more than one painful or blistering childhood sunburn (yes or no), reporting a family history of skin cancer (yes or no/don’t know), skin type (Fitzpatrick scale [119], grouped as fair [type I and II], medium [type III] and dark [type IV and VI]), eye colour (light [blue, grey, or green] or dark [hazel and darker]), hair colour [blonde/red or brown/darker], number of sunburns reported in the previous summer [0, 1, or 2+], and race [Caucasian or non-Caucasian]. Job and training variables included education, industry, job title, a description of job tasks, and length of employment at the current job. Industry and occupation information was used to group workers into three broad job type categories. These were marine construction (pile driving, working on-board boats, dock building); land-based construction (road building and paving, concrete finishers, and residential construction); and horticultural/non-construction jobs (golf course maintenance, wildlife protection, landscaping).

Data on sun protection behaviours was collected via Likert-scale answers (never, rarely, sometimes, often, or always use the protective behaviour) to the questions outlined in Figure 3.1. Questions on behaviours were asked identically but separately for workdays and leisure time. In addition, workers were asked how often they spent time in the sun in order to get a tan (Likert scale answers), as well as how many hours they typically spent outdoors between the hours of 10am and 4pm during their work and leisure time.

The leisure and work sun protection scores were calculated by scoring each answer to the questions in Figure 1 (wearing sunscreen, a sleeved shirt, a hat, sunglasses, and seeking shade) on a 5-point ordinal scale ranging from 0 (never using the behaviour) to 4 (always using the behaviour) [120, 121]. A composite score of all 5 behaviours was created by averaging these
scores, separately for workdays (work protection score) and leisure days (leisure protection score), leading to scores that would fall in the range of 0 – 4.

<table>
<thead>
<tr>
<th>For the following questions, think about what you do when you are outside AT WORK during the summer on a warm sunny day.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How often do you wear SUNSCREEN?</td>
</tr>
<tr>
<td>2. How often do you wear a SHIRT WITH SLEEVES that cover your shoulders?</td>
</tr>
<tr>
<td>3. How often do you wear a HAT?</td>
</tr>
<tr>
<td>4. How often do you stay in the SHADE or UNDER AN UMBRELLA?</td>
</tr>
<tr>
<td>5. How often do you wear SUNGLASSES?</td>
</tr>
</tbody>
</table>

Figure 3.1 Sun protection behavior questions from the Outdoor Workers Project questionnaire

3.2.4 Statistical analysis

Multiple linear regression using SAS PROC GLM [122] (version 9.3) was used to model the determinants of sun protection behaviour scores separately for work and leisure. Manual backwards stepwise regression was used, and the potential explanatory variables initially considered for entry into the model were demographic (sex, age, race), personal risk factors (skin type, hair and eye colour, having had more than one childhood sunburn, number of sunburns the previous summer, family history of skin cancer), and training and work characteristics (education, job group, job tenure). The best fit model was chosen by removing the least statistically significant variable one by one, and leaving those variables in the model where the p-values were below 0.2. Model results were produced as least squares means for ease of interpretation.

3.3 Results

Seventy-eight outdoor workers were recruited for participation in the Outdoor Workers Project. For this study, one outdoor worker was excluded due to an incomplete questionnaire, for a total of 77 outdoor workers in the analytic sample. Most of the outdoor workers were male (95%), young (mean age of 38 years), and Caucasian (95%) (Table 3.1). Less than 15% of the workers identified themselves as having Fitzpatrick Skin Type I or II (most susceptible to sunburn). Despite this, the majority of outdoor workers reported experiencing more than one severe childhood sunburn (58%), and nearly a third had two or more sunburns in the previous summer.
Table 3.1 Description of participants and explanatory variables in Outdoor Workers Project (n = 77)

<table>
<thead>
<tr>
<th>Variable</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sex</strong></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>73 (95)</td>
</tr>
<tr>
<td>Female</td>
<td>4 (5)</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td></td>
</tr>
<tr>
<td>Mean, range</td>
<td>38.0 (18 – 69)</td>
</tr>
<tr>
<td><strong>Education</strong></td>
<td></td>
</tr>
<tr>
<td>High school or equivalent, or less</td>
<td>22 (29)</td>
</tr>
<tr>
<td>Some college, trade school, or university</td>
<td>24 (31)</td>
</tr>
<tr>
<td>Completed college, trade, or university</td>
<td>27 (35)</td>
</tr>
<tr>
<td>Prefer not to say</td>
<td>4 (5)</td>
</tr>
<tr>
<td><strong>Race</strong></td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td>73 (95)</td>
</tr>
<tr>
<td>Other</td>
<td>4 (5)</td>
</tr>
<tr>
<td><strong>Skin type</strong></td>
<td></td>
</tr>
<tr>
<td>I and II (very fair and fair)</td>
<td>11 (14)</td>
</tr>
<tr>
<td>III (white to olive)</td>
<td>43 (56)</td>
</tr>
<tr>
<td>IV - V (olive to brown and darker)</td>
<td>23 (30)</td>
</tr>
<tr>
<td><strong>Eye colour</strong></td>
<td></td>
</tr>
<tr>
<td>Light blue, grey, or green</td>
<td>49 (64)</td>
</tr>
<tr>
<td>Hazel or darker</td>
<td>28 (36)</td>
</tr>
<tr>
<td><strong>Hair colour</strong></td>
<td></td>
</tr>
<tr>
<td>Red or blonde</td>
<td>9 (12)</td>
</tr>
<tr>
<td>Light brown or darker</td>
<td>68 (88)</td>
</tr>
<tr>
<td><strong>Number of sunburns in the previous summer</strong></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>22 (29)</td>
</tr>
<tr>
<td>1</td>
<td>32 (42)</td>
</tr>
<tr>
<td>2+</td>
<td>23 (30)</td>
</tr>
<tr>
<td><strong>More than 1 severe childhood sunburn?</strong></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>45 (58)</td>
</tr>
<tr>
<td>No</td>
<td>32 (42)</td>
</tr>
<tr>
<td><strong>Family history of skin cancer</strong></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>10 (13)</td>
</tr>
<tr>
<td>No or don’t know</td>
<td>67 (87)</td>
</tr>
<tr>
<td><strong>Job group</strong></td>
<td></td>
</tr>
<tr>
<td>Marine construction</td>
<td>33 (43)</td>
</tr>
<tr>
<td>Land-based construction</td>
<td>29 (38)</td>
</tr>
<tr>
<td>Horticultural/non-construction</td>
<td>15 (19)</td>
</tr>
<tr>
<td><strong>Time at current job (years)</strong></td>
<td></td>
</tr>
<tr>
<td>Mean, range</td>
<td>11.8 (0.25 – 38)</td>
</tr>
</tbody>
</table>
Most workers were educated (completed at least some college or trade school, 66%) (Table 3.1), and the largest industrial group was heavy and civil engineering construction (49%), followed by highway, street and bridge construction (20%) (data not shown). The most common occupations were heavy equipment operators (27%) and concrete finishers (13%) (data not shown). Overall, most workers were employed in marine construction and land-based construction (85% of all workers, Table 3.1). Workers had relatively long job tenure at their current position, at nearly 12 years on average.

3.3.1 Sun-related behaviours at work and leisure

Detailed data on sun protection behaviours in outdoor workers at work and leisure are presented in Table 3.2. A large majority of participants report that, while at work, they ‘often or always’ use sunglasses (74%), long-sleeved shirts (82%), and hats (79%) (note: the hats worn are typically hard hats without a wide brim). In contrast, very few workers (8%) reported that they sought shade as a protective behaviour at work, and only 29% reported regular use of sunscreen. In comparison to strategies employed while at leisure, sunscreen and sunglasses use ‘often or always’ was the same or similar. However, outdoor workers were less likely to wear long-sleeved shirts during leisure activities (62% compared to 82% while at work), less likely to wear a hat (53% versus 79% while at work), but more likely to seek shade (23% versus 8% while at work). Most workers did not often spend time in the sun in order to get a tan (only 12% reported this practice ‘often or always’).

Table 3.2 Frequency distributions for sun-protection behaviours for outdoor workers (n=77)

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>Never/Rarely/Sometimes (%)</th>
<th>Often/always (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Work</td>
<td>Leisure</td>
</tr>
<tr>
<td>Wear sunscreen</td>
<td>55 (71)</td>
<td>55 (71)</td>
</tr>
<tr>
<td>Wear a shirt with sleeves</td>
<td>14 (18)</td>
<td>29 (38)</td>
</tr>
<tr>
<td>Wear a hat</td>
<td>16 (21)</td>
<td>36 (47)</td>
</tr>
<tr>
<td>Stay in the shade or under umbrella</td>
<td>71 (92)</td>
<td>59 (77)</td>
</tr>
<tr>
<td>Wear sunglasses</td>
<td>20 (26)</td>
<td>17 (22)</td>
</tr>
<tr>
<td>Spend time in the sun to get a tan</td>
<td>-</td>
<td>68 (88)</td>
</tr>
</tbody>
</table>

Sun protection scores and measures of time spent outdoors both at work and leisure are presented in Table 3.3. Overall, outdoor workers spend more time outdoors between the hours of 10am and 4pm while at work than they do on weekends (6.0 hours versus 4.0 hours). Outdoor workers in this sample had slightly higher sun protection scores at work than at leisure (2.5 versus 2.3) (Table 3.3).
Table 3.3 Hours spent outside, and sun protection scores (work and leisure) among outdoor workers

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Mode</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours spent outside on workdays*</td>
<td>-</td>
<td>6.0</td>
<td>≤1 – 6</td>
</tr>
<tr>
<td>Hours spent outside at leisure*</td>
<td>-</td>
<td>4.0</td>
<td>≤1 – 6</td>
</tr>
<tr>
<td>Workplace sun protection score (max range 0 – 4)</td>
<td>2.5</td>
<td>-</td>
<td>1.0 – 3.8</td>
</tr>
<tr>
<td>Leisure time sun protection score (max range 0 – 4)</td>
<td>2.3</td>
<td>-</td>
<td>0.8 – 3.6</td>
</tr>
</tbody>
</table>

*Between the hours of 10am and 4pm (i.e. max value = 6); categorical responses presented as mode

3.3.2 Determinants of sun protection scores

The results of the determinants of behaviour models (one for work and one for leisure) are presented in Table 3.4. In the work sun protection behaviour model, those with fair and medium skin types (higher risk for sunburn and skin cancer) had a higher mean protection score than those with the darkest skin types (2.27 and 2.73 for medium and fair skin types, respectively, versus 1.92 for darker skin types). Those with light-coloured eyes (higher risk for skin cancer) also had a higher mean sun protection score while at work. Interestingly, light-haired workers had lower work sun protection scores than those with darker hair (2.09 for light hair compared to 2.52 for darker hair); this result was marginally significant. In addition, older workers tended to have higher work sun protection scores (an increase of 0.008 in the score per year older, p=0.11; results not shown as they cannot be presented as least squares means). The construction-focused job groups also had higher sun protection scores at work than those who were not in construction, which is expected as construction sites tended to require hard hats and sleeved shirts for safety reasons.

For the leisure time sun protection score model, similar patterns to the work score model were observed, with the strongest relationship being with skin type (1.99 and 2.45 for medium and fair skin, respectively compared to 1.65 for darker skin types). Eye colour was not important in this model, but similar relationships with hair colour and age were observed, though again, these did not meet statistical significance. Those who report spending time in the sun in order to get a tan had lower sun protection scores than those who did not try to get a tan (p=0.02), showing that the desire for a tan leads to less sun protective behaviours.

In both models, race, sex, number of sunburns, childhood sunburn, or family history of skin cancer were not determining factors for the sun protection scores. Time spent out of doors at work or at leisure were also not important to the models. Job tenure was highly correlated with age (Pearson correlation coefficient=0.75, p<0.0001), so these two variables were examined in separate models; age was a stronger predictor.
### Table 3.4 Determinants of sun protection scores

<table>
<thead>
<tr>
<th>Effect</th>
<th>Determinants of work protection score*</th>
<th>Determinants of leisure protection score**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean score (SE)</td>
<td>p-value</td>
</tr>
<tr>
<td>Skin type†</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fairest</td>
<td>2.73 (0.18)</td>
<td>0.0018</td>
</tr>
<tr>
<td>Medium</td>
<td>2.27 (0.12)</td>
<td></td>
</tr>
<tr>
<td>Darkest</td>
<td>1.92 (0.17)</td>
<td></td>
</tr>
<tr>
<td>Eye colour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue, grey or green</td>
<td>2.42 (0.11)</td>
<td>0.1054</td>
</tr>
<tr>
<td>Brown and darker</td>
<td>2.20 (0.15)</td>
<td></td>
</tr>
<tr>
<td>Hair colour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blonde or red</td>
<td>2.09 (0.20)</td>
<td>0.0507</td>
</tr>
<tr>
<td>Brown and darker</td>
<td>2.52 (0.09)</td>
<td></td>
</tr>
<tr>
<td>Job group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land construction</td>
<td>2.41 (0.13)</td>
<td>0.1817</td>
</tr>
<tr>
<td>Marine construction</td>
<td>2.41 (0.13)</td>
<td></td>
</tr>
<tr>
<td>Horticultural/other</td>
<td>2.10 (0.18)</td>
<td></td>
</tr>
<tr>
<td>Spends time in sun to tan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sometimes, rarely, never</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Often or always</td>
<td>1.79 (0.21)</td>
<td></td>
</tr>
</tbody>
</table>

*Variables initially offered to the work model included those noted plus race, sex, childhood sunburn, family history of skin cancer, number of sunburns the previous summer, education, job tenure, hours spent outside at work. Age is included in the model as well; results not shown.

**Variables initially offered to the leisure model included those noted plus race, sex, childhood sunburn, family history of skin cancer, number of sunburns the previous summer, education, hours spent outside at leisure.

†Fairest= Fitzpatrick Type I or II; Medium= Fitzpatrick Type III; Darkest= Fitzpatrick Type IV or higher. Age is included in the model as well; results not shown.

### 3.4 Discussion

This study extends previous work on sun protection behaviours in outdoor workers, especially in Canada, where there have been very few studies. In addition, the focus was on high-risk, male-dominated industries, a group that has been typically underserved by studies of sun protection and skin cancer prevention. In general, the prevalence of sun protection behaviours used at work by participants in the Outdoor Workers Project (OWP) was relatively high. The prevalence of wearing a shirt with sleeves that cover the shoulders or a hat at work was both approximately 80%. This is higher than reported by the Canadian Second National Sun Safety Survey (NSS2), where 59% of men reported wearing protective clothing at work, and 62% reported covering their heads. This is likely due to the large number of workers in construction in the OWP, who are required to wear hats and shirts for safety purposes by their workplaces [40]. Similarly, workday sunglass use was higher in the OWP at 74%, versus 52% in men in the NSS2. Sunscreen use was low among men in both studies (29% in the OWP versus 20% in the
NSS2). However, it is evident from a recent review of outdoor workers’ sun protection behaviours that there is wide variability in the prevalence of occupational sun protection behaviour use across studies, locations, and industries [112]. For example, of the studies included in the review, regular sunscreen use ranged from 2% (among Californian farmers [113]) to 85% (among Australian lifeguards [123]). Shade-seeking was the least-used protective behaviour at work in the OWP (8% using this behaviour often/always); notably, workers sought shade three times as often in their leisure time. Workers in the OWP reported less sun protection in leisure time compared to the general Canadian population. Shade-seeking and sunscreen use in leisure time was reported often or always by 44% and 40% of Canadians, respectively, compared to 23% and 29% in the current study [124]. The use of protective clothing, however, was reported at similar levels (47% in the general population, and 41% for hats and 48% for sleeved shirts in the current study). Outdoor workers tend to protect themselves from the sun at lower levels than the general population in many countries.

The only statistically significant determinant of sun protection behaviour scores at work was skin type. However, there was evidence of relationships, although not statistically significant, for eye colour, hair colour, job type, and increasing age. Skin type was also important for leisure time sun protection scores, in addition to a propensity for tanning leading to less protective behaviours being adopted. Lighter skinned (Skin Type I and II) individuals are at higher risk of sunburn and skin cancer, and outdoor workers with lighter skin types have been found to practice better sun protective behaviours in several studies [111, 125-127]. It is likely that the more acute (and thus tangible) risk of sunburn for light-skinned workers is a motivator for using more sun protection; public health campaigns on sun protection could also be a factor driving these particular workers to use better protection at work.

Older workers had higher sun protection scores both at work and leisure, which is a well-known relationship in outdoor workers in general [127]. Among young people, especially young men, there is a tendency to report less risk-averse behaviours and also higher ability to cope with risk [68], which might explain why younger workers in the OWP protected themselves less often from the damaging effects of solar UVR. In addition, there is a strong relationship with older age and a decline in the belief that tanned skin is healthier and/or more attractive [128], and indeed age was negatively correlated with reporting purposefully tanning in the OWP (Pearson’s correlation coefficient = -0.27, p = 0.014).

Workers were less likely to wear hats and shirts in their leisure time (82% wearing hats at work versus 62% at leisure; 79% wearing sleeved shirts at work versus 53% at leisure), suggesting the safety requirement for the construction workers is leading to higher sun protection scores while at work. A natural experiment study in Australia showed that outdoor workers who were required to wear sun protection at work had less sun-damaged skin than those who could voluntarily use sun protection provided at work [129]. Even though sun protection was not the motivation behind requiring workers to wear hats and shirts at work in the OWP, it may have provided sun protection as an unintended positive consequence.
The Outdoor Workers Project was designed to examine UVR exposure levels in fairly limited industry groups (construction, though this was expanded further to increase the sample size), and many of the 77 participants worked for a few larger employers. This relatively small sample size and purposeful sampling strategy led to a more homogenous study group, and likely contributed to the low number of discernible determinants of sun protection behaviours, even expected ones (such as race or time spent outside). However, it is not surprising that skin type emerged as the strongest predictor of using better sun protection as this is a strong correlate of risk for both sunburn (acute) and skin cancer (chronic), and it is also linked to other risk factors that did not emerge as important in the model (such as having a family history of skin cancer, or the number of sunburns reported in the previous summer).

Despite the aforementioned limitations, this is the first study of sun protective behaviours in Canadian outdoor workers. Focusing on men in the construction industries is also an important contribution, as this is a group at particularly high risk of solar UVR exposure, but for which little research exists. Sun exposure studies in outdoor workers traditionally focused on recreation workforces that are more female, though we know that men tend to protect themselves from the effects of the sun less, receive the majority of skin cancer diagnoses, and have higher mortality rates than women [1,112]. The construction industry is second only to the primary industries (agriculture, forestry, fishing, hunting) in terms of the number of workers exposed to solar UVR at work in Canada, and both of these industries are heavily male-dominated [Peters, 2015 252 /id]. Of the over 340,000 construction workers exposed to solar UVR in Canada, over half of them are expected to work outdoors at least 75% of their workdays (high exposure). Other national studies of sun protection in outdoor workers have had no information on jobs, precluding the examination of any differences by industry or occupation [40,43].

A further limitation in this study was the small number of women, which did not allow for examination of sun protective behaviours by sex/gender (and sex was not a determinant of sun protection behaviours, likely due to the small number of women in the study [n=4]). This would have been a useful exercise, given that gender is the demographic characteristic most commonly associated with sun protection behaviours (in particular, sunscreen use) [66]. However, the construction industry in Canada is largely male (89% men, compared to an overall distribution in Canada’s labour force of 53% men), so this was not an unexpected result in this study, and in fact the distribution by sex in the Outdoor Workers Project (95% men) was similar to the national figures [90]. Thus, the results of this study should be assumed to be more applicable to men, and further studies in Canadian women who work outdoors are warranted. This study also highlighted the infrequent use of sunscreen among male outdoor workers, both at work and in leisure time. While sunscreen is the last line of defense in sun protection, it is easier to use than shade-seeking in an outdoor workplace, and is underused in men in general [3]. Successful interventions to reduce occupational sun exposure in men could be different than for women.

This study provided evidence that outdoor workers at higher risk of sunburn and skin cancer (i.e. lighter skinned individuals) were more likely to practice sun protection behaviours while at
work as well as at leisure. It also showed that older workers were likely to practice more protective behaviours. Outdoor workers rarely sought shade while at work, but they were more likely to do so in their leisure time. Several policy implications can be identified from these observations. Firstly, though provision of shade is difficult in an outdoor workplace setting, workers may be more likely to use it if it were available, given that they seek shade much more often outside of work than they do while at work. Moveable shade structures could be useful where work is in a relatively limited area (as sometimes occurs in the construction industry), and more research is warranted in this area [128]. Secondly, requiring workers to wear a shirt and hat at work could be an effective strategy for reducing sunburn and skin cancer risk in Canada as these behaviours seem to be correlated with occupational health and safety requirements. Lastly, focusing on newer/younger construction workers with sun protection messaging may be an effective way to increase their use of sun protection while at work and over their working careers.
Chapter 4: Measured levels of solar UVR in outdoor workers

4.1 Introduction

Solar ultraviolet radiation (UVR) was originally classified by the International Agency for Research on Cancer as a known human carcinogen in 1992 [131] and confirmed in 2012, noting sufficient evidence for melanoma and non-melanoma skin cancers, as well as positive associations with lip cancer, ocular melanoma, and conjunctival squamous cell carcinoma [55]. Non-melanoma skin cancer (NMSC, including squamous and basal cell carcinoma) in particular is of concern for outdoor workers, a group at risk of high cumulative (and often acute) exposure to solar UVR [27, 53]. In Canada, NMSC is the most commonly diagnosed malignancy [1], and approximately 1.5 million Canadians are at risk of solar UVR exposure at work [132].

The relationship between having an outdoor job (occupational exposure to UVR) and being diagnosed with basal cell carcinoma BCC has only recently been accepted, and this is because BCC was long thought to be linked to short-term, acute exposures (perhaps especially in early life) [27]. This is generally accepted to be true, but the influence of longer-term, cumulative exposure is now also recognized as contributing to the development of BCC. The relationship between outdoor work and squamous cell carcinoma (SCC) has been accepted for much longer, though the approximate doubling of risk seen in meta-analyses is presumed to be an underestimate due to the effect of exposure misclassification (sun-exposed people being classified as unexposed, and crude exposure assessments in general) [53]. The relationship between occupational exposure and malignant melanoma is more tenuous, and indeed in many studies, outdoor workers were at lower risk [29]. Even this, however, has begun to be challenged as some researchers have found increased risk of certain subtypes of melanoma and/or body location of lesions and cumulative exposure to solar UVR [133].

Most studies of UVR exposure (in both occupational and recreational settings) use self-reports of working outdoors (yes/no), or time spent out of doors as their exposure assessment method [70]. This is despite the fact that personal exposure measurements show wide variability in UVR dose, and that both personal and ambient environmental factors play a role in this variability [134-137]. It is possible that the lack of objective measurements of solar UVR exposure has contributed to the complicated (and evolving understanding of) epidemiology of skin cancer with respect to timing of exposure as well as pattern, and that better characterization of the hazard could lead to better estimates of the dose-response relationship between solar UVR exposure and skin cancers [138]. Despite this, personal dosimetry for occupational solar UVR exposure has not previously been done in Canadian workplaces. Knowledge of the relevant exposure parameters is important for understanding the etiology of the various types of skin cancer, but it is also relevant for skin cancer prevention messaging.

Over eighty percent of the outdoor workers in Canada are men [132], and men receive the majority of NMSC diagnoses, likely due to both their occupational exposure, as well as different patterns of sun protective behaviours. The construction industry has the largest exposed
industrial group in Canada (343,000 exposed workers, followed by 264,000 in farming) [132], and few studies worldwide have focused on this high-risk group of outdoor workers previously [136, 139, 140], instead focusing in agriculture or recreational industries (e.g. skiing).

Weather and other meteorological conditions have a strong relationship with the general strength of solar UVR at the earth’s surface, as well as variability in the measurements. It is therefore important to take them into account in studies of UVR exposure levels. In addition, forecast tools (such as the UV Canada application for smart phones, which compiles daily weather and UV Index forecast data into a simple form [141]) allow for the ability to plan ahead with respect to sun protection behaviours required for a work day, for example. The UV Index is based on the erythemal action spectrum (as described in Chapter 1) and offers a simple and unitless guideline for public health purposes. The UV Index is calculated by multiplying the erythemal irradiance by 40 [10].

The objective of this study was to objectively measure personal solar UVR exposure in outdoor workers across several different worksites and industrial locations in Vancouver, Canada, and to examine whether personal, work, or meteorological factors are more important determinants of exposure levels. This data is important for demonstrating the feasibility for other occupational researchers of UVR dosimetry studies in a heavy industrial setting, in addition to providing valuable study design information and recommendations for future studies. It will also provide data to identify the highest-risk occupations in terms of UVR exposure level, which will inform the development of prevention initiatives for skin cancer.

4.2 Methods

4.2.1 Study design

The Outdoor Workers Project (OWP) was a cross-sectional UVR exposure assessment study that took place in the summer of 2013 (data collection from July to September) in the greater Vancouver, British Columbia area. As part of the OWP, workers wore an electronic UVR dosimeter badge for approximately five working days, and filled out an activity diary once per hour during measurement days. Workers completed a questionnaire that provided data on demographics, skin cancer risk factors, job characteristics, and sun protection behaviours and habits undertaken while at work as well as in leisure time. In addition, weather forecasts including UV Index were recorded from Environment Canada for each sampling day. The current study focuses on the exposure measurements from the UVR dosimeter badges.

4.2.2 Study sample (inclusion/exclusion, recruitment methods)

Participants in the Outdoor Workers Project (OWP) were recruited via building trade unions and by approaching companies with outdoor operations via their health and safety staff. Several individual workers also learned about the study via word-of-mouth and were also invited to participate (note that many of these workers were not construction workers per se, but did
work outdoors). Worksites needed to be amenable to having at least two site visits by the study coordinator (on the first and last days of sampling), and workers were provided with a study information sheet prior to their decision to participate. On the first morning of the scheduled sampling work week, eligible workers were provided with a study invitation letter and those that consented to participate were given a short training session on the components of the questionnaire and instructions for using the UVR dosimeter badges. Eligibility was met by those workers who were 18 years of age or older, and who spent at least part of an average workday outdoors. Although the target was five work days per worker during their sampling week, those with more or less than five days of were also invited to participate. The study protocol was approved by the University of British Columbia Research Ethics Board (certificate H11-01272).

4.2.3 Data collection: UVR dosimeters and meteorology

Personal solar UVR exposure data was collected using personal electronic dosimeters (Mark II) (Figure 4.1). The dosimeters’ functionality is described in detail elsewhere [71], but in brief, UVR is detected using aluminum-gallium-nitride photodiodes (AlGaN), which have a spectral response that closely matches the erythemal action spectrum for human skin [8]. The dosimeters contain a processor with an analog converter allowing the reading of UV irradiance, battery voltage, and temperature at pre-specified sampling intervals [142]. The analog measurements for UVR exposure were converted to UV Index via side-by-side calibration with UV Index measures from the Brewer Spectrophotometer Network (Environment Canada, Richmond, British Columbia site) [143]. The Brewer Spectrophotometer measures spectral UV irradiation (between 295 and 325 nanometers) every 10 to 20 minutes during daylight hours. The dosimeters used in this study were placed on top of the Brewer on three sunny days in June 2013, and separate calibration curves were created for each dosimeter badge.

The dosimeters are wireless and data-logging, and were programmed to take a measurement once per minute between the hours of 8AM and 5PM. Each per-minute measurement was converted to a UV Index measure via the calibration curve, and the standard erythemal dose (SED) for each day was calculated by adding up each per-minute SED by day [144], as per equations [1] and [2]:

\[
[1] \quad \text{SED}_{\text{day}} = \sum_{8\text{AM}-5\text{PM}} \left( \text{SED}_{\text{minute}} \right) \\
[2] \quad \text{SED}_{\text{minute}} = \left( \text{UVIndex}_{\text{minute}} \right) \times (0.025 \text{ W/m}^2) \times (60 \text{ seconds/minute}) \times \frac{100 \text{ Joules/m}^2}{100 \text{ Joules/m}^2} \\
\]

where \( \text{SED}_{\text{day}} \) is the Standard Erythemal Dose per work day in Joules/m\(^2\); \( \text{UVIndex}_{\text{minute}} \) is the UV Index (unitless) measured from the dosimeter badge per minute; 0.025 W/m\(^2\) is the standard unit for solar irradiance per unit of UV Index; and 1 Joule = 1 Watt*second.

Workers were asked to don their dosimeters each morning of the sampling week and wear them for the full workday. The dosimeters can be worn on a wrist band, pinned to a lapel, or on
a hardhat; workers were given the option of any placement they preferred; placement was noted by the researchers.

![Figure 4.1 The Mark II dosimeter](image)

Meteorological data was noted each morning of the study from the Environment Canada forecast for general weather and forecasted maximum UV Index [141]. In addition, the actual maximum UV Index was noted from the Brewer Spectrophotometer for each day.

### 4.2.4 Variables and statistical analyses

Data collected via the study questionnaire is described fully in Chapter 3. Questionnaire variables on demographics and risk factors for skin cancer (age, sex, education, reporting more than one painful or blistering childhood sunburn (yes or no), family history of skin cancer, skin type (Fitzpatrick scale [119], grouped as fair [type I and II], medium [type III] and dark [type IV and V]), eye colour (light [blue, grey, or green] or dark [hazel and darker]), hair colour ([blonde/red or brown/darker]) and job information were included in the present study to explore differences in UVR exposure levels among the study participants. Jobs were categorized into horticultural, land-based construction (e.g. road building), and marine-based construction (e.g. dock building), and length of time at the current job was also included as a potential predictor variable. Time spent outdoors between the hours of 8AM and 5PM (the period the dosimeters were collecting data) was included, as reported via the daily task diaries.

In addition to examining the daily SED values themselves, values were compared to the available maximum SED for each calendar day, as calculated from measurements taken at the nearest Brewer Spectrophotometer. In order to calculate the maximum daily ambient UVR, UV Index data from the Richmond Brewer Spectrophotometer was downloaded for each study day from Environment Canada. The Brewer measures UV Index once every 10 to 20 minutes, so the SED accumulated per minute was calculated by integrating forward in time, assuming that the UV Index remained the same as the previous measure until the next time stamped measure occurred. $\text{SED}_{\text{max}}$ was then calculated for each study day by adding up all the individual per-minute values, as in the calculation of individual exposures from the dosimeters (see equations [1] and [2]). Each person’s SED per day was compared to the maximum available for that day as a percentage of maximum ($\text{SED}_{\%\text{max}}$).
Data for a day was removed when it indicated that the worker had not donned their badge on that day, or that it was covered or oriented incorrectly (i.e. an ‘idle’ day). Days were considered idle when they had an SED\%_{\text{max}} of less than the 5\text{th} percentile, calculated separately by the reported number of hours spent outside at work between 10AM and 4PM. In this way, lower SED\%_{\text{max}} values were allowed to remain in as “true” samples if workers reported spending shorter times out of doors.

SAS PROC MIXED [122] (version 9.3) was used for univariate analyses to control for repeated measures per person and per calendar day. Differences in the mean SED_{\text{day}} and SED\%_{\text{max}} between groups were tested (after natural log transformation) using the F statistic. PROC MIXED was also used to create two separate marginal models examining the relationships between job, weather and demographic variables and 1) the natural-log-transformed standard erythemal dose (SED_{\text{day}}); as well as 2) the log-transformed SED\%_{\text{max}}. As in univariate analyses, repeated measurements on the same subject during the sampling week were controlled for, as were repeated measurements on the same date. A manual backwards stepwise regression method was used. Potential explanatory variables initially considered for entry into the models were demographic (sex, age, race), training and work characteristics (education, job group, job tenure, hours spent outside each day), weather forecast (grouped into sunny, mixed, or cloudy sampling work days, as available via the UV Canada app), and the predicted high UV Index value for each day (considered both as a categorical and continuous variable, also available from the UV Canada app). The best fit model was chosen by removing the non- significant variables (p-value of less than 0.20) one by one until the best fitting model was arrived at (decided using the Akaike information criterion (AIC)). Age and job tenure were highly correlated, so they were modeled separately.

4.3 Results

4.3.1 Demographics and skin cancer risk factors

In total, seventy-eight outdoor workers were recruited for participation in the Outdoor Workers Project. For this study, seventy-three workers were included; two were excluded due to lost dosimeter badges, one due to dosimeter malfunction, one for not completing the questionnaire, and one because all sampled dates were deemed ‘idle’ (the badge was not worn properly, or not worn at all).

There were initially 336 exposure days collected among the seventy-three included participants; 18 days were determined to be “idle” days where participants were unlikely to have donned their badges, leaving a total of 318 included exposure days, and 73 participants with at least one active sampling day. In total, 40 different calendar days were represented in the study.

Participants were mostly male (96%), relatively young (mean age 38 years), and Caucasian (96%) (Table 4.1). Despite only 15\% of the workers reporting very fair or fair skin, most workers (73\%) reported at least one sunburn the previous summer. The majority of participants worked
in construction-related industries; 19% worked in horticultural or other industries (these outdoor workers outside of construction were recruited by word-of-mouth to increase sample size) (Table 4.1).

Table 4.1 Demographic and risk factor data for exposure monitoring in the Outdoor Workers Project

<table>
<thead>
<tr>
<th>Variable</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>70 (96)</td>
</tr>
<tr>
<td>Female</td>
<td>3 (4)</td>
</tr>
<tr>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>Mean, range</td>
<td>38.3 (18 – 69)</td>
</tr>
<tr>
<td>Education</td>
<td></td>
</tr>
<tr>
<td>High school or equivalent, or less</td>
<td>21 (29)</td>
</tr>
<tr>
<td>Some college, trade school, or university</td>
<td>23 (32)</td>
</tr>
<tr>
<td>Completed college, trade, or university</td>
<td>25 (34)</td>
</tr>
<tr>
<td>Prefer not to say</td>
<td>4 (5)</td>
</tr>
<tr>
<td>Race</td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td>70 (96)</td>
</tr>
<tr>
<td>Other</td>
<td>3 (4)</td>
</tr>
<tr>
<td>Skin type</td>
<td></td>
</tr>
<tr>
<td>I and II (very fair and fair)</td>
<td>11 (15)</td>
</tr>
<tr>
<td>III (white to olive)</td>
<td>40 (55)</td>
</tr>
<tr>
<td>IV - V (olive to brown and darker)</td>
<td>22 (30)</td>
</tr>
<tr>
<td>Eye colour</td>
<td></td>
</tr>
<tr>
<td>Light blue, grey, or green</td>
<td>48 (66)</td>
</tr>
<tr>
<td>Hazel or darker</td>
<td>25 (34)</td>
</tr>
<tr>
<td>Hair colour</td>
<td></td>
</tr>
<tr>
<td>Red or blonde</td>
<td>8 (11)</td>
</tr>
<tr>
<td>Light brown or darker</td>
<td>65 (89)</td>
</tr>
<tr>
<td>Number of sunburns in the previous summer</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>20 (27)</td>
</tr>
<tr>
<td>1</td>
<td>32 (44)</td>
</tr>
<tr>
<td>2+</td>
<td>21 (29)</td>
</tr>
<tr>
<td>More than 1 severe childhood sunburn?</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>42 (58)</td>
</tr>
<tr>
<td>No</td>
<td>31 (42)</td>
</tr>
<tr>
<td>Family history of skin cancer</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>8 (11)</td>
</tr>
<tr>
<td>No or don’t know</td>
<td>65 (89)</td>
</tr>
<tr>
<td>Job group</td>
<td></td>
</tr>
<tr>
<td>Marine construction</td>
<td>31 (43)</td>
</tr>
<tr>
<td>Land-based construction</td>
<td>28 (38)</td>
</tr>
<tr>
<td>Horticultural/non-construction</td>
<td>14 (19)</td>
</tr>
<tr>
<td>Time at current job (years)</td>
<td></td>
</tr>
<tr>
<td>Mean, range</td>
<td>11.9 (0.25 – 38)</td>
</tr>
</tbody>
</table>
### 4.3.2 Meteorological data

The data collection period (40 calendar days between July and September 2013) was mostly sunny (25 of 40 days) and warm (mean 23°C, range 19 to 29 °C). Measures of the daily forecasted maximum UV Index and temperature (predicted by Environment Canada’s forecasting and recorded each morning of the study) are shown in Table 4.2, as are the actual daily maximum UV Indexes as recorded at Environment Canada’s Brewer spectrophotometer station in Richmond, British Columbia, and the calculated maximum dose available per day in SED between the hours of 8AM and 5PM. Agreement between the predicted and actual UV Index measures was very high (Pearson correlation coefficient 0.89, p<0.0001).

Daily high temperatures were also correlated with UV Index variables (Pearson correlations of 0.50 and 0.51 for the predicted UVI and actual UVI, p values 0.001 and 0.0008, respectively), but the correlation was less strong due to several relatively cool days with high UV Index values. The daily available UV dose varied with weather as well, and showed that available UV dose was more than double on sunny compared to cloudy days.

Table 4.2 Meteorological results by daily weather forecast (calendar days in study = 40 between July and September, 2013)

<table>
<thead>
<tr>
<th>Forecast</th>
<th>n days (%)</th>
<th>Forecasted maximum UVI (mean, sd)</th>
<th>Actual maximum UVI (mean, sd)</th>
<th>Maximum available UV dose (SED)</th>
<th>Maximum forecasted temperature (mean, sd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunny</td>
<td>25 (63)</td>
<td>7.1 (0.67)</td>
<td>6.9 (0.78)</td>
<td>36.6 (5.6)</td>
<td>23.4°C (2.1)</td>
</tr>
<tr>
<td>Mixed sun/cloud</td>
<td>8 (20)</td>
<td>5.0 (0.76)</td>
<td>4.9 (0.99)</td>
<td>21.0 (6.6)</td>
<td>21.3°C (1.2)</td>
</tr>
<tr>
<td>Cloudy</td>
<td>7 (17)</td>
<td>3.1 (1.80)</td>
<td>4.1 (1.70)</td>
<td>16.9 (8.1)</td>
<td>21.0°C (1.5)</td>
</tr>
</tbody>
</table>

**Ultraviolet radiation (UVR) dosimetry results**

Histograms for each exposure variable of interest (SED\textsubscript{day} and SED\textsubscript{%max}) are shown in Figures 1a and 1b. Both sets of data were log-normally distributed; the two variables were also highly correlated (Pearson correlation coefficient of 0.98), which suggests that the available ambient UVR was a major contributor to exposure level. Most measurements of SED fell in the category centered around 1 SED, and the pattern was the same for SED\textsubscript{%max}; the majority of measurements were around 2% of the daily maximum SED available, but did get as high as 53% (Figure 4.2).
Figure 4.2 Distribution of ultraviolet radiation dose measurements in the Outdoor Workers Project (n=318 measurements)

Univariate results are shown in Table 4.3, including uncorrected means (which discounts repeated measures) and corrected means with associated p-values from one predictor-variable marginal models. The overall uncorrected arithmetic mean of daily UV measures (n=318) was 2.39 Standard Erythemal Doses (SED), and 6.84% of the total UV available per day (Table 4.3). The maximum recorded SED\textsubscript{day} was over 19; that same measurement accounted for 53% of available UV on the day it was measured (meaning the worker received over 50% of the total available UVR on that day).

Daily mean exposure in the OWP (accounting for repeated calendar day and repeated measurements per worker) was 1.08 Standard Erythemal Doses (SED\textsubscript{day}), and 3.3% of the available daily maximum UV dose. None of the demographic or personal risk factors had a statistically significant relationship with either SED\textsubscript{day} or SED\textsubscript{%max}. Although non-significant, there were interesting results for sex, race, and skin type as presented in Table 4.3 (others not shown). Women’s exposure levels were notably higher than men’s (2.69 SED versus 1.04), but there were just three female subjects, one of whom had the highest SED in the study. Non-Caucasians and those with skin type IV-VI also had notable higher UV radiation exposure (both SED\textsubscript{day} and SED\textsubscript{%max}).

UV exposure differed by job group, with horticultural/non-construction workers receiving less than half the average SED\textsubscript{day} doses of the construction workers (Table 4.3). Placement of the dosimeter badge on the body also seemed to matter (though not statistically, likely due to most people choosing the lapel); hard hat placement showed higher levels than either the lapel or wrist band placement. The most important factors considered were daily forecasted UV Index and weather forecast. Both were strongly statistically significant and showed clear patterns of higher SED measures with increasing sunny weather and UV Index values (Table 4.3). Older
# Ultraviolet radiation (UVR) Monitoring Results for Daily SED Measurements and % of Maximum Available UVR

<table>
<thead>
<tr>
<th>Uncorrected for repeated measures</th>
<th>SED&lt;sub&gt;day&lt;/sub&gt; *</th>
<th>Range</th>
<th>SED%&lt;sub&gt;max&lt;/sub&gt; †</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>n=318 measurements</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arithmetic mean (SD)</td>
<td>2.39 (2.86)</td>
<td>0.01 – 19.2</td>
<td>6.84 (7.85)</td>
<td>0.03 – 53.3</td>
</tr>
<tr>
<td>Geometric mean (GSD)</td>
<td>1.18 (3.84)</td>
<td></td>
<td>3.63 (3.51)</td>
<td></td>
</tr>
<tr>
<td><strong>Corrected for repeated date and subject</strong></td>
<td>SED&lt;sub&gt;day&lt;/sub&gt; (SE)</td>
<td>p-value</td>
<td>SED%&lt;sub&gt;max&lt;/sub&gt; (SE)</td>
<td>p-value</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All subjects (n=73)</td>
<td>1.08 (1.14)</td>
<td>-</td>
<td>3.33 (1.13)</td>
<td>-</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male (n=70)</td>
<td>1.04 (1.15)</td>
<td>0.161</td>
<td>3.22 (1.13)</td>
<td>0.190</td>
</tr>
<tr>
<td>Female (n=3)</td>
<td>2.69 (1.93)</td>
<td></td>
<td>7.34 (1.84)</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All subjects (β, SE)</td>
<td>-0.015 (0.011)</td>
<td>0.169</td>
<td>-0.017</td>
<td>0.086</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caucasian (n=70)</td>
<td>1.06 (1.15)</td>
<td>0.495</td>
<td>3.27 (1.14)</td>
<td>0.482</td>
</tr>
<tr>
<td>Other (n=3)</td>
<td>1.70 (1.97)</td>
<td></td>
<td>5.14 (1.87)</td>
<td></td>
</tr>
<tr>
<td>Skin type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I and II (very fair and fair) (n=11)</td>
<td>1.05 (1.04)</td>
<td>0.124</td>
<td>3.17 (1.37)</td>
<td>0.165</td>
</tr>
<tr>
<td>III (white to olive) (n=40)</td>
<td>0.87 (1.20)</td>
<td></td>
<td>2.78 (1.18)</td>
<td></td>
</tr>
<tr>
<td>IV - VI (olive to brown and darker) (n=22)</td>
<td>1.62 (1.27)</td>
<td></td>
<td>4.75 (1.25)</td>
<td></td>
</tr>
<tr>
<td>Job group</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine construction (n=31)</td>
<td>1.28 (1.22)</td>
<td>0.021</td>
<td>3.61 (1.20)</td>
<td>0.071</td>
</tr>
<tr>
<td>Land-based construction (n=28)</td>
<td>1.30 (1.23)</td>
<td></td>
<td>4.07 (1.22)</td>
<td></td>
</tr>
<tr>
<td>Horticultural/non-construction (n=14)</td>
<td>0.50 (1.35)</td>
<td></td>
<td>1.86 (1.32)</td>
<td></td>
</tr>
<tr>
<td>Placement of badge</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lapel (n=62)</td>
<td>1.05 (1.16)</td>
<td>0.519</td>
<td>3.26 (1.15)</td>
<td>0.431</td>
</tr>
<tr>
<td>Hard hat (n=5)</td>
<td>1.87 (1.68)</td>
<td></td>
<td>5.79 (1.61)</td>
<td></td>
</tr>
<tr>
<td>Wrist band (n=6)</td>
<td>0.90 (1.60)</td>
<td></td>
<td>2.60 (1.54)</td>
<td></td>
</tr>
<tr>
<td>Hours outside per day (at work)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All subjects (β, SE)</td>
<td>0.35 (0.03)</td>
<td>&lt;0.0001</td>
<td>0.30 (0.03)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Forecasted weather</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloudy (n=7)</td>
<td>0.24 (1.36)</td>
<td>&lt;0.0001</td>
<td>1.06 (1.34)</td>
<td>0.001</td>
</tr>
<tr>
<td>Mixed (n=8)</td>
<td>0.74 (1.19)</td>
<td></td>
<td>2.97 (1.18)</td>
<td></td>
</tr>
<tr>
<td>Sunny (n=25)</td>
<td>1.27 (1.14)</td>
<td></td>
<td>3.63 (1.13)</td>
<td></td>
</tr>
<tr>
<td>Predicted UVIndex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low (S2)</td>
<td>0.15 (1.70)</td>
<td>&lt;0.0001</td>
<td>1.26 (1.69)</td>
<td>0.041</td>
</tr>
<tr>
<td>Moderate (3 – 5)</td>
<td>0.43 (1.23)</td>
<td></td>
<td>2.20 (1.22)</td>
<td></td>
</tr>
<tr>
<td>High (6 – 7)</td>
<td>1.23 (1.13)</td>
<td></td>
<td>3.52 (1.14)</td>
<td></td>
</tr>
<tr>
<td>Very high (8 – 10)</td>
<td>1.37 (1.18)</td>
<td></td>
<td>3.82 (1.18)</td>
<td></td>
</tr>
</tbody>
</table>

*SED<sub>day</sub> is an erythemally-weighted measure of radiant exposure per work day. 1 SED=100 Joules/m²
†SED%<sub>max</sub> is the percent of total available SED received per day (i.e. SED<sub>day</sub> ÷ SED<sub>max</sub> x 100).
† Corrected: results are estimates from a marginal model containing the variable noted in the leftmost column as the only predictor, controlling for repeated subject and calendar date.
aged workers appeared to have lower UV exposure as well (age treated as continuous), though these results were not significant (p=0.086 for the SED\%max measure). The continuous measure of hours spent outdoors each day (from daily activity diaries) was also related to both UV exposure measurements (p<0.0001).

Estimated coefficients for the two separate marginal models (one for SED\textsubscript{day} and one for SED\%max) are shown in Table 4.4. Since the log-transformed SED\textsubscript{day} and SED\%max values were used, final predicted values from the models should be exponentiated to obtain an interpretable estimate (worked example can be found below). In the model examining predictors of SED\textsubscript{day}, only time spent outdoors (reported daily from workers’ task diaries), the daily forecasted UV Index, and the general weather forecast were significant predictors. In the model examining predictors of SED\%max, similar results were found, except that the daily predicted UV Index did not remain in the final model. In this model, only time spent outdoors and the forecast were significant predictors of the percentage of the total available UV dose a worker received. None of the personal factors (such as age, sex, race, and skin cancer risk factors, or occupation) were important in either of the models.

Table 4.4 Model results: predictors of SED\textsubscript{day} (Standard Erythemal Dose per day) and SED\%max (Standard Erythemal Dose as a percentage of total available ultraviolet radiation)

<table>
<thead>
<tr>
<th>Predictor</th>
<th>SED\textsubscript{day} model*</th>
<th>SED%max model*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient (SE)</td>
<td>p-value</td>
</tr>
<tr>
<td>Intercept</td>
<td>-2.7 (0.50)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Time outside</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours outside / day (task diaries)</td>
<td>0.31 (0.03)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Forecast</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloudy</td>
<td>-0.90 (0.32)</td>
<td>0.008</td>
</tr>
<tr>
<td>Mixed</td>
<td>-0.24 (0.16)</td>
<td>0.153</td>
</tr>
<tr>
<td>Sunny</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Predicted UV Index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous variable (1 – 8)</td>
<td>0.13 (0.07)</td>
<td>0.052</td>
</tr>
</tbody>
</table>

*Demographic, work and environment variables were offered to multivariable models, but only statistically significant results are presented for the final models.

These models can be interpreted by considering the equations [3] and [5] for the SED\textsubscript{day} model and equations [4] and [6] for the SED\%max model, as shown below:

\[3\] \( \ln(\text{SED}_{\text{day}}) = 0.31(\text{# hours outside}) + \beta_3(\text{forecast}) + 0.13(\text{UVIndex}) - 2.7 \)

\[4\] \( \ln(\text{SED}_{\%\max}) = 0.29(\text{# hours outside}) + \beta_3(\text{forecast}) - 0.53 \)
So for example, for worker i, on a sunny day with predicted UV Index of 7, where he spent 8 hours outdoors, we have:

\[ \text{[5] } \ln(\text{SED}_{\text{day}}) = 0.31(8) \times [-0.90(0) - 0.24(0) + 0(\text{sunny}=1)] + 0.13(7) - 2.7 \]
\[ = 2.48 \times [0 - 0 + 0] + 0.91 - 2.7 \]
\[ = 0.69 \]
\[ \text{SED}_{\text{day}} = \exp(0.69) \]
\[ = 1.99 \text{ SED} \]

\[ \text{[6] } \ln(\text{SED}_{\%\text{max}}) = 0.29(8) \times [-0.84(0) - 0.09(0) + 0(\text{sunny}=1)] - 0.53 \]
\[ = 2.32 \times [0 - 0 + 0] - 0.53 \]
\[ = 1.79 \]
\[ \text{SED}_{\%\text{max}} = \exp(1.79) \]
\[ = 5.99\% \]

Worker i could thus expect to receive a daily dose of about 2 SED, and 6% of the available UV dose for that hypothetical day. This SED is high enough to produce a perceptible sunburn in a fair-skinned individual, and is approximately six times higher than the recommended exposure limit (0.3 SED).

### 4.3.3 Sensitivity analyses

The daily forecasted UV Index value was treated as categories (as it is presented in Table 4.3), and age was also examined as categories, but model fit was better when both of these variables were treated as continuous variables (this was the case for both models, though forecasted UV Index did not remain in the SED$_{\%\text{max}}$ model). Actual UV Index (measured) was also examined, but the overall results did not change, so the predicted values were used instead (as this measure is available to the general public and could therefore be more easily used for prevention purposes). A variety of categorizations for job title were attempted, however there were several categories with very few workers, so the broad categorization of marine construction, land construction and horticultural work were retained.

### 4.4 Discussion

The Outdoor Workers Project was the first study to objectively measure real-time, personal exposure to solar UVR among an occupational group in Canada. It is important to collect dosimetry data for outdoor workers’ exposure to solar UVR from all over the world in order to validate models and compare risks, due to the extremely high exposure variability found both within city and between locations. Participants in the OWP were exposed to highly variable amounts of solar UVR, even under similar ambient conditions, as reflected in the lognormal distribution of exposure results. Exposure ranged from 0.01 SED to 19.2 (0.03% to 53% of total available UVR). These results are consistent with other results from countries at comparable
lattitudes. For example, a study of gardening workers in Denmark and Ireland showed mean daily SED values of 0.97 in Ireland and 1.6 SED in Ireland, though the range in exposure was not as high; maximum values of 2.7 and 3.8 in Denmark and Ireland, respectively [145]. However, this was likely driven both by the available ambient UVR in Vancouver during the study, as well as difference in tasks between gardeners and workers in the OWP. The mean ambient SED in the OWP was 29.9 SED, while it was only 17.8 in Copenhagen and 19.1 in Copenhagen. Workers in the study by Thieden and colleagues also took shady lunch breaks, which did not happen consistently in the OWP. Values recorded in the present study were lower than has been seen in studies of lifeguards in the United States (median values depending on city ranged from 1.7 in Portland, OR, to 3.3 in Austin, Texas; note that these workers only spent an average of 4 hours outdoors). Exposures in construction workers in Australia are much higher, with median values of around 5 to 10, but as high as 32 SED in a single day [136].

Ambient UVR exposure depends on a large number of different factors, including latitude, weather (cloud cover), altitude, season, time of day, and surface reflection [146]. Personal exposure depends on these factors in addition to time spent outdoors (frequency of exposure), timing of exposure (intensity), work tasks performed, and shade availability and/or use [134, 147, 148], as well as other sun protective behaviours. Therefore it is not surprising that wide variation in exposure levels occur, even under identical atmospheric conditions. Although dosimeter placement was not retained as significant in the final model (likely due to most workers choosing the lapel placement), the orientation of the badges did change the exposure measures (i.e. hard hat placement led to increased exposure). In a larger study, the effect of both badge placement as well as orientation of the body should be included as potential determinants of exposure level [52]. In this study, information on tasks performed each day was collected (so that work-related behaviours (including posture) could be assessed as contributors to variability in measured doses), but the data was not usable as this information was not recorded reliably. For example, many workers were observed completing their task diaries on the last day of the study, and simplified their tasks down to one or two that they said they performed all week. Future studies with a particular interest in task-specific variability should account for this by either having someone else record tasks, or designing the study in a workplace setting where workers are allotted more time to complete task diaries. Alternatively, the use of electronic survey devices that are quick and easy to fill out, with the potential for reminders to be sent could be investigated in future studies to improve task-based data collection.

In the univariate results, there were significant differences between exposure levels by job group, with those in construction having higher exposure levels than those in horticultural-based jobs (~1.3 versus 0.5 SED), but this did not remain as a significant predictor in the final model. In an Australian study of construction workers, Gies and Wright also found wide variability between different job titles, with cabinet makers, painters and construction inspectors receiving about 1/10th the median UVR exposure of pavers or machine operators (doggers) [136]. Interestingly, though workers in that study had higher exposure than in the OWP (and were also measured for less time), the general exposure pattern by job was similar to
the current study, with pavers, traffic controllers, and riggers having higher exposure than supervisory or carpentry workers (data not shown).

Inability to distinguish exposure between jobs well was likely due to a small number of workers overall (n=73), and especially due to small numbers of workers per job description. Other studies in outdoor workers have found widely varying exposure levels, and it has been suggested that outdoor workers have considerable within-group variation in their UVR exposure, which could also contribute to a lack of effect from occupational group [149]. A recent Spanish study found median values of around 3 SED per day (compared to approximately 1 SED in the OWP), which is within an expected realm, given the latitude and weather in Spain as compared to Vancouver [150]. Other studies in Australia and New Zealand (where most measurement studies have been done) have found exposure levels that are much higher (an order of magnitude), but again this is very likely due to higher ambient exposure to solar UVR in those countries [135, 136, 149, 151, 152]. In addition, it is difficult to compare directly the actual measured exposure levels in the OWP and other studies from around the world. Reasons for this include a lack of standardized measurement methods, differences in study design, and the wide variety of environmental and location-specific contributors to daily UVR exposure in outdoor workers; however this study provides the first Canadian values for future comparison with other more local studies (i.e. in North America).

Exposure limits have been proposed for ultraviolet radiation in general, but many countries (Canada included) do not adopt the standard as it applies to UVR from the sun in particular. For example, the International Commission on Non-Ionizing Radiation Protection recommends a maximum daily personal dose of 30 J/m², or 0.3 SED [107]. At an ambient UV Index level of 6, this exposure limit would be exceeded in just over 13 minutes; a fair-skinned person could expect to have a sunburn in just over 22 minutes [107]. In the OWP, many workers exceeded this exposure limit regularly. An exposure of approximately 1.5 to 3.0 SED is required to produce a sunburn in a fair-skinned person with untanned skin, for reference. Of the 318 measured days in the OWP, 143 (45%) exceeded 1.5 SED, showing that some workers were certainly at risk of sunburn during the study, and indeed, most people reported at least one sunburn the previous summer (73%; Table 4.1).

The fact that the only variables that consistently predicted solar UVR exposure in the OWP were time spent outdoors and meteorological conditions has some interesting implications for the design of prevention initiatives. In effect, taken at face value, these results suggest that the highest risk workers can be identified only by their estimated time spent outdoors, coupled with some basic forecast information and predicted UV Index values by day. In reality, there is more nuance, since larger studies are required to tease out the potential personal, workplace, and task-related determinants of exposure that could not be addressed in the current study. However, if a worksite were interested in a simple tool to identify those workers at highest risk, knowing their time spent outdoors and the weather for a workday would be enough to distinguish at least some of the workers that would benefit from exposure reduction strategies.
There are limitations to this analysis that should be noted. Firstly, the sample size was relatively small and limited to a set geographic location. In order to properly characterize solar UVR exposure in outdoor workers in Canada, a larger study would be required. In addition, exposures in some other parts of the country are likely to be higher due to higher available ambient UVR in the summer months. In this way, results from this study should not be extrapolated beyond construction and horticultural workers in the Vancouver area, and even then, could be underestimated due to many workers in the study finishing work in the early to mid-afternoon. However, these industries often have earlier start schedules, and so other workers in the area working for different companies very likely have similar exposure levels to those people in the OWP.

The dosimeter badges used in this study are only just gaining in popularity, and remain relatively new. Most previous dosimetry studies have used polysulphone badges rather than electronic ones (or different electronic ones), and this may hinder direct comparisons between results from other studies. However, the badges rely on the same principles for measurement and were calibrated with similar instruments and weighting functions, and the results were certainly in the range of what might be expected, even given geographic differences between Canada and other locations. In several Danish studies, which are likely to have the most similar results to Canada, exposure levels were very similar, ranging from daily SED measures of 0.75 to 3.8 [137, 145, 147].

Based on the data collected in the OWP, construction workers in Canada could be at risk of significant exposure to solar UVR in the summer months. The mean exposure levels found were over 1.0 SED, which is more than 3 times the recommended exposure limit, and a small number of study participants routinely received UVR doses that were much higher. However, the only significant predictors of UVR were weather and UV Index, as well as how much time was spent outside. From a cancer prevention point of view, this suggests that occupational health policies for skin cancer prevention that employ a warning system based on predicted UV Index level and weather could help to lower outdoor workers’ exposure to UVR on particularly high risk days.
Chapter 5: Occupational exposure to solar ultraviolet radiation and reduced risk of prostate cancer

5.1 Introduction

Excluding skin cancers, prostate cancer is the most common malignancy diagnosed in Canadian men, and the third most common cause of cancer-related deaths among men [1]. Unlike skin cancer being mostly attributed to ultraviolet radiation (UVR) exposure, the environmental causes of prostate cancer remain unclear. Other than personal and genetic characteristics including older age, race, screening history and family history being associated with prostate cancer, consistent risk factors have not been identified [153]. Interest in identifying occupational and environmental causes for prostate cancer is strong [154] as a result of widely varying rates of prostate cancer by country and population-based groups.

The geographical variation in cancer rates (lower cancer rates closer to the equator) prompted many researchers to investigate ultraviolet radiation (UVR) exposure due to its spatial variability, and ecological studies have shown that exposure to UVR may lead to lower risks of colorectal (in particular), breast, ovarian and prostate cancers [155-157]. The interest was plausible because of a hypothesized protective effect of vitamin D exposure, and the striking racial differences in prostate cancer risk (for example, American black men of African ancestry in one study had a 58% increased risk compared to white men of European ancestry); darker-skinned people are much more likely to have vitamin D deficiencies than lighter-skinned people due to less ability to produce it endogenously through UVR exposure pathways [158]. However, the relationship between skin pigmentation, the ability to synthesize vitamin D, and the fact that the sun sensitive (despite being technically able to produce more vitamin D) more often avoid the sun to reduce sunburn and skin cancer risk complicates the relationship between UVR exposure and prostate cancer risk [159]. Indeed, several studies have not found a relationship between either sun exposure or vitamin D and reduced prostate cancer risk [160-162].

Despite these potentially complex relationships, a decreased risk of prostate cancer with increased solar UVR exposure has been detected before. Bodiwala et al. in particular carried out a study of English men (comparing prostate cancer cases to men with benign prostatic conditions) that collected detailed information on solar UVR exposure over the life course and showed significant reductions in risk of developing prostate cancer, especially in the highest exposure category [157, 163]. These studies used residential histories [155, 164] or self-reported indicators of solar UVR as their exposure metrics [163, 165]. In addition, a large prospective study of UVR exposure and the risk of various cancers in the US used individual-level, ground-level estimates of residential UVR derived from satellite data to examine cancer risk; they found significantly decreased risks of prostate cancer in all exposure categories relative to the comparison group [166].
Since outdoor workers receive about six to eight times the yearly exposure to solar UVR than indoor workers, a useful identifier of cumulative UVR exposure is whether or not a person works outdoors [127]. In a Netherlands-based study of prostate cancer occurring in patients with a previous skin cancer diagnosis, a significantly decreased standardized incidence ratio (SIR) for prostate cancer of 0.89 was found for all skin cancer types, and it was lowest for those with squamous cell carcinoma in particular (0.84), the skin malignancy most strongly linked to cumulative, occupational exposure [167]. In a study by John et al., non-significant reductions in risk of Prostate cancer (OR 0.73, 95% CI 0.46 – 1.11) were noted in those with the highest occupational exposure, and exposure was self-reported as never, occasional, or frequent by participants [168]. The balance of evidence here suggests a decreased risk with higher occupational exposure to UVR.

The purpose of this study was to test the hypothesis, in the context of a Canadian population-based case-control study, that higher cumulative occupational UVR exposure reduces the risk of prostate cancer; the purpose was also to improve on UVR exposure measures for epidemiological studies. Exposure assessment and epidemiological analysis was done in two phases: 1) using just the solar job exposure matrix (SUNJEM) described in Chapter 2 to assign all jobs into high, moderate and low categories of exposure based on time spent outside each workday; and 2) enhancing this JEM by applying estimated ground-level UVR exposure measures (obtained from satellite data) to each exposed job over time for more refined measures based on geographic location.

5.2 Methods

5.2.1 Study population

The National Enhanced Cancer Surveillance System (NECSS) is a large, multi-site case-control study that was designed to facilitate investigations of the environmental causes of cancer in Canada [169]. The study included cases with 14 different types of cancers from eight of the ten provinces, frequency matched with population controls to obtain a similar age and sex-distribution for all cases [170]. Detailed methods for the NECSS data collection are published elsewhere [169-171]; briefly, mailed questionnaires (with telephone follow-up where necessary) were used to obtain full residential and occupational histories, as well as detailed information on risk factors for cancer. The response rate for cases and controls was 69% respectively. Questions included ethnicity, relationship status, education, income, smoking, height, weight, physical activity (variety of measures including strenuousness of activity), diet (60-item food frequency measure), and exposure to several occupational carcinogens (including pesticides, cadmium, radiation, coal, tar, pitch and soot).

For these analyses, prostate cancer cases and controls interviewed between 1994 and 1997 were used; interviews were conducted within 6 months after diagnosis in all provinces except Ontario, where this lag time was approximately one year. Prostate cancer cases were identified from the provincial cancer registries (which identifies nearly all cancer cases), and were
histologically confirmed. Controls were obtained differently by province. In Prince Edward Island, British Columbia, Nova Scotia, Saskatchewan and Manitoba, controls were selected randomly from the provincial health insurance registries. In Ontario, Ministry of Finance data was used to generate a stratified random sample of controls, and in Newfoundland and Alberta random digit dialing was used to recruit controls. Controls were age-matched based on the entire cohort (i.e. for all cancer cases), so the controls were slightly younger than cases for prostate cancer. The cases and controls were both limited to men between aged 50 and 75 years for this analysis because younger diagnoses for prostate cancer are rare and more likely to reflect genetic susceptibility rather than occupational or environmental exposure, and people over the age of 75 years were not included in the NECSS due to logistical and anticipated recall issues [170]. People were excluded from the analysis if they had missing job information (title or years), or missing residential histories if they had an outdoor job at that time and location could not be determined from the job title.

5.2.2 Exposure assessment

A previously-created job exposure matrix (SUNJEM) for outdoor work (see Chapter 2) was used to assign exposure for all outdoor jobs in either low (up to 2 hours per day), moderate (2 to 4 hours) or high (≥6 hours) categories based on time spent outdoors by job [132]. If more than one job title was noted in the description, two job codes (and where applicable, two industry codes) were assigned. If the primary job was flagged as exposed, then the secondary job was usually ignored, unless it implied that the person also worked in management or ownership; in which cases the level was dropped by one scale point. If the primary job was not flagged as exposed but the secondary one was, exposure was added on a case-by-case basis. Part time and seasonal jobs were weighted in time-relevant exposure metrics (e.g. years in an outdoor job) by dividing the number of years in that job by half. In SUNJEM, if there is uncertainty about whether a low exposed job should be flagged or not, the default is to leave it as unexposed unless there is a compelling reason from the job description to flag it as exposed. For this reason, only 50 jobs were flagged in the low category of exposure, so these jobs were combined with the moderately exposed jobs in this analysis.

In addition to the JEM, satellite measures of UV-B were available from the Global UV (glUV) project developed at the Helmholtz Centre for Environmental Research [62]. This data is freely available and was linked to the latitude/longitude of each residence for each person in the study, assuming that the home location would be relatively close to the work location. The unit of measure for this data is Joules/m²/day, which can be converted to the Standard Erythemal Dose by dividing by 100.

The analysis was divided into two parts: one using only information from the JEM, and one adding in information from the satellite UV measurements, to understand the impact of more refined geographically weighted measures for UVR on the risk relationship with prostate cancer. Exposure metrics considered for the JEM-only analysis included ever exposed (yes/no), ever exposed to a high UVR exposure category job (yes/no), number of years of outdoor work
(in quartiles), and number of years in a high UVR exposure category job (also in quartiles). Exposure metrics considered in the satellite-enhanced analyses included total ambient UVR summed up over the years of outdoor work (dividing ambient UVR measures in half if the job was in the low JEM category), and total UV summed up over the years of outdoor work in the high category only. For these cumulative measures, quartiles of exposure were used for exposure metrics (measurement unit of SED*years).

5.2.3 Statistical analyses

SAS PROC LOGISTIC (version 9.3) was used to create separate models for each exposure metric, modeling prostate cancer case as the outcome. Due to the sampling differences for controls across provinces and the age structure of cases compared to controls, all bivariate analyses were calculated as minimally adjusted odds ratios so that these two variables (province and 5-year age category) were always accounted for in the presentation of results. Predictive models to ascertain broadly the risk factors for prostate cancer have been previously published on this dataset [170]. The purpose of this analysis was to investigate the relationship between different measures of UVR exposure in outdoor workers and risk of prostate cancer, and so the list of covariates considered was much smaller than in the previous analysis, and was directed at ensuring the inclusion of potential confounders (i.e. the variable must be related to both the exposure (being an outdoor worker) and the outcome). The variables considered were ethnicity (grouped as European descent, European descent with higher likelihood of darker skin types (Italian, Spanish, Greek, Portuguese) Asian, Indian, First Nations, Black, or Other), smoking (in pack-years), marital status (married or common-law, single/divorced/separated, or widowed), percent of lifetime lived in urban areas (estimated from residential histories), total career length in years, education (in years), income (adjusted for number of people per household, to represent income adequacy), body mass index (BMI), hours of moderate and strenuous physical activity per month, total servings of dairy, fruit, and vegetables per week, and self-reported exposure to pesticides, cadmium, or asphalt fumes (suspected occupational risk factors for prostate cancer).

Each potential confounder was considered in a minimally-adjusted logistic model (i.e. adjusted for province and 5-year age category) with each exposure metric only, to evaluate its effect on the exposure variable alone. Variables that made little difference to the exposure-related odds ratios were not considered for inclusion in the final models. Variables that changed the odds ratios of the exposure metrics appreciably (>10%) were added to the models. Ethnicity was always included (along with age and province) because it is one of the few known risk factors for prostate cancer. Particular interest was paid to variables that could be related to the likelihood for prostate cancer screening (e.g. marital status and urban living, both expected to increase the likelihood for screening), as screening information was not collected in the NECSS.
5.3 Results

There were 4,346 men in the original dataset, of which 634 were outside of the specified age range (50-75), and a further 377 either had no recorded job histories (n=104), missing job titles or dates of employment (n=264), or missing information on their location during times when they had an outdoor job (n=9), leaving a total of 3,335 people available for this analysis (1638 cases and 1697 controls) (Figure 5.1). The population in general had 13,249 different jobs (approximately 4 per person, on average). Nearly 19% of these were classified as outdoor jobs (n=2,496). The most frequent outdoor jobs were farmers/agriculture workers (n=919), trades labourers (n=209), heavy equipment operators (n=169) and carpenters (n=133). Of the outdoor jobs, the small number of low exposure category jobs (n=50) were combined with the moderate category for a total of 711 jobs, leaving the remaining 1,785 in the high category (>75% of workdays spent outdoors). The longest job held by each subject was also calculated, and the most common jobs held by case status are shown in Table 5.1.

![Figure 5.1 Inclusion and exclusion criteria for a case-control study of prostate cancer and UVR exposure, National Enhanced Cancer Surveillance System, from 1994 to 1997](image)

The relationships between the six different metrics of occupational UVR exposure and the odds of prostate cancer are presented in Table 5.2, as six different models. Each model has minimally-adjusted odds ratios (OR) (age and province), as well as a fully-adjusted model. The
covariates that remained in the fully adjusted models were the same for all 6 models and included race/ethnicity, relationship status, percent of time lived in urban areas, and total career length. In terms of the covariates, people of Indian and Asian heritage were at significantly reduced risk of prostate cancer (OR 0.15 and 0.22, respectively in minimally-adjusted models), while black and First Nations people were at increased risk (results not significant). Single men were less likely to have prostate cancer than married men (OR 0.78, 95%CI 0.6 – 1.0), and people with higher percentages of their lives spent in urban areas than rural areas were less likely to have prostate cancer. Length of career in years was included as well (to attempt to control for the healthy worker effect) in the adjusted models (OR 1.01, 95%CI 1.002 – 1.02; results not shown).

Table 5.1 Longest jobs (over the working life) held in a case-control study of prostate cancer and UVR exposure, National Enhanced Cancer Surveillance System

<table>
<thead>
<tr>
<th>Broad occupational groups</th>
<th>Cases (n, %)</th>
<th>Typical titles (cases)</th>
<th>Controls (n,% )</th>
<th>Typical titles (controls)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management</td>
<td>265 (16)</td>
<td>Senior managers (n=47), retail managers (n=27)</td>
<td>259 (15)</td>
<td>Senior managers (n=67), retail managers (n=34)</td>
</tr>
<tr>
<td>Business, finance, administration</td>
<td>143 (9)</td>
<td>Scheduling/distributing (n=33), admin. officers (n=26)</td>
<td>130 (8)</td>
<td>Admin. officers (n=30), general office work (n=19)</td>
</tr>
<tr>
<td>Natural and applied sciences</td>
<td>139 (8)</td>
<td>Engineers (n=27), engineering techs (n=24)</td>
<td>120 (7)</td>
<td>Engineers (n=26), engineering techs (n=19)</td>
</tr>
<tr>
<td>Health</td>
<td>29 (2)</td>
<td>Physicians (n=15)</td>
<td>47 (3)</td>
<td>Physicians (n=21)</td>
</tr>
<tr>
<td>Social science, education, government services</td>
<td>92 (6)</td>
<td>High school teachers (n=38), professors (n=18)</td>
<td>84 (5)</td>
<td>High school teachers (n=38), professors (n=18)</td>
</tr>
<tr>
<td>Art, culture, recreation</td>
<td>16 (1)</td>
<td>Writers (n=2)</td>
<td>23 (1)</td>
<td>Performing artists (n=9)</td>
</tr>
<tr>
<td>Sales and service</td>
<td>200 (12)</td>
<td>Police/firefighters (n=33), wholesale trade (n=31)</td>
<td>206 (12)</td>
<td>Retail sales (n=33), protective services (n=28)</td>
</tr>
<tr>
<td>Trades, transport and equipment operators</td>
<td>467 (29)</td>
<td>Drivers (n=73), car mechanics (n=47)</td>
<td>488 (29)</td>
<td>Drivers (n=81), contractors (n=43)</td>
</tr>
<tr>
<td>Occupations unique to primary industry</td>
<td>190 (12)</td>
<td>Farm managers (n=76), agriculture and horticulture (n=67)</td>
<td>217 (13)</td>
<td>Agriculture &amp; horticulture (n=102), farm managers (n=57)</td>
</tr>
<tr>
<td>Occupations unique to processing, manufacturing, utilities</td>
<td>97 (6)</td>
<td>Processing supervisors (n=17), labourers (n=14)</td>
<td>123 (7)</td>
<td>Wood processing operators (n=18), food processing operators (n=16)</td>
</tr>
</tbody>
</table>
Table 5.2 Exposure to occupational solar ultraviolet radiation (UVR) and prostate cancer risk: minimally adjusted and fully adjusted models

<table>
<thead>
<tr>
<th>Variables</th>
<th>Cases (n=1638)</th>
<th>Controls (n=1697)</th>
<th>Minimally adjusted odds ratio (OR)‡</th>
<th>Fully adjusted odds ratio (OR)†</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MODEL 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ever exposed</td>
<td>45%</td>
<td>42%</td>
<td>1.10 (0.95 – 1.30)</td>
<td>0.99 (0.85 – 1.20)</td>
</tr>
<tr>
<td><strong>MODEL 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ever high job</td>
<td>36%</td>
<td>35%</td>
<td>1.03 (0.89 – 1.20)</td>
<td>0.92 (0.78 – 1.10)</td>
</tr>
<tr>
<td><strong>MODEL 3: Exposure years</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>55%</td>
<td>58%</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>&gt;0 - &lt;10</td>
<td>18%</td>
<td>15%</td>
<td>1.19 (0.98 – 1.45)</td>
<td>1.08 (0.89 – 1.32)</td>
</tr>
<tr>
<td>10 - &lt;35</td>
<td>16%</td>
<td>15%</td>
<td>1.17 (0.95 – 1.43)</td>
<td>1.05 (0.85 – 1.29)</td>
</tr>
<tr>
<td>≥35</td>
<td>11%</td>
<td>12%</td>
<td>0.89 (0.40 – 1.12)</td>
<td>0.71 (0.55 – 0.93)</td>
</tr>
<tr>
<td>p-value for trend</td>
<td></td>
<td></td>
<td></td>
<td>0.907</td>
</tr>
<tr>
<td><strong>MODEL 4: Exposure years, only high category jobs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>64%</td>
<td>65%</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>&gt;0 - &lt;10</td>
<td>15%</td>
<td>13%</td>
<td>1.10 (0.90 – 1.35)</td>
<td>0.99 (0.80 – 1.23)</td>
</tr>
<tr>
<td>10 - &lt;35</td>
<td>13%</td>
<td>12%</td>
<td>1.05 (0.84 – 1.30)</td>
<td>0.93 (0.74 – 1.23)</td>
</tr>
<tr>
<td>≥35</td>
<td>8.7%</td>
<td>9.4%</td>
<td>0.91 (0.70 – 1.17)</td>
<td>0.74 (0.55 – 0.99)</td>
</tr>
<tr>
<td>p-value for trend</td>
<td></td>
<td></td>
<td></td>
<td>0.832</td>
</tr>
<tr>
<td><strong>MODEL 5: UV quartiles, all exposed jobs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>55%</td>
<td>58%</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>&gt;0 – &lt;76 SED-yrs</td>
<td>11%</td>
<td>10%</td>
<td>1.17 (0.93 – 1.48)</td>
<td>1.08 (0.86 – 1.37)</td>
</tr>
<tr>
<td>76 – &lt;232 SED-yrs</td>
<td>12%</td>
<td>10%</td>
<td>1.20 (0.95 – 1.51)</td>
<td>1.07 (0.84 – 1.36)</td>
</tr>
<tr>
<td>232 – 523 SED-yrs</td>
<td>11%</td>
<td>11%</td>
<td>1.07 (0.85 – 1.35)</td>
<td>0.95 (0.74 – 1.21)</td>
</tr>
<tr>
<td>≥523 SED-yrs</td>
<td>10%</td>
<td>11%</td>
<td>0.96 (0.75 – 1.21)</td>
<td>0.78 (0.60 – 1.03)</td>
</tr>
<tr>
<td>p-value for trend</td>
<td></td>
<td></td>
<td></td>
<td>0.738</td>
</tr>
<tr>
<td><strong>MODEL 6: UV quartiles, only high category jobs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>64%</td>
<td>66%</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>&gt;0 – &lt;86 SED-yrs</td>
<td>9.0%</td>
<td>8.5%</td>
<td>1.07 (0.84 – 1.38)</td>
<td>0.99 (0.77 – 1.29)</td>
</tr>
<tr>
<td>86 – &lt;245 SED-yrs</td>
<td>9.4%</td>
<td>8.4%</td>
<td>1.09 (0.85 – 1.40)</td>
<td>0.97 (0.75 – 1.26)</td>
</tr>
<tr>
<td>245 – 629 SED-yrs</td>
<td>9.4%</td>
<td>8.1%</td>
<td>1.14 (0.83 – 1.46)</td>
<td>0.99 (0.76 – 1.29)</td>
</tr>
<tr>
<td>≥629 SED-yrs</td>
<td>8.1%</td>
<td>9.4%</td>
<td>0.85 (0.66 – 1.10)</td>
<td>0.68 (0.51 – 0.92)</td>
</tr>
<tr>
<td>p-value for trend</td>
<td></td>
<td></td>
<td></td>
<td>0.849</td>
</tr>
<tr>
<td><strong>COVARIATES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Race/ethnicity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Western European Caucasian</td>
<td>90%</td>
<td>85%</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Italian/ Spanish/ Greek/ Portuguese</td>
<td>5.3%</td>
<td>6.5%</td>
<td>0.75 (0.56 – 1.02)</td>
<td>0.81 (0.59 – 1.10)</td>
</tr>
<tr>
<td>Asian</td>
<td>1.4%</td>
<td>4.4%</td>
<td>0.22 (0.14 – 0.36)</td>
<td>0.25 (0.15 – 0.41)</td>
</tr>
<tr>
<td>Indian</td>
<td>0.6%</td>
<td>2.5%</td>
<td>0.15 (0.07 – 0.31)</td>
<td>0.17 (0.08 – 0.35)</td>
</tr>
<tr>
<td>First Nations</td>
<td>1.3%</td>
<td>1.0%</td>
<td>1.30 (0.67 – 2.52)</td>
<td>1.30 (0.67 – 2.58)</td>
</tr>
<tr>
<td>Black</td>
<td>0.6%</td>
<td>0.5%</td>
<td>1.47 (0.56 – 3.86)</td>
<td>1.81 (0.68 – 4.78)</td>
</tr>
<tr>
<td>Other</td>
<td>0.4%</td>
<td>0.4%</td>
<td>1.04 (0.36 – 2.97)</td>
<td>1.10 (0.39 – 3.20)</td>
</tr>
</tbody>
</table>
## COVARIATES continued

<table>
<thead>
<tr>
<th>Relationship status</th>
<th>Cases (n=1638)</th>
<th>Controls (n=1697)</th>
<th>Minimally adjusted odds ratio (OR)</th>
<th>Fully adjusted odds ratio (OR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Married/Common law</td>
<td>88%</td>
<td>86%</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Single/Divorced/Other</td>
<td>7.4%</td>
<td>9.5%</td>
<td>0.78 (0.60 – 1.00)</td>
<td>0.76 (0.58 – 0.98)</td>
</tr>
<tr>
<td>Widowed</td>
<td>4.9%</td>
<td>4.1%</td>
<td>1.17 (0.83 – 1.65)</td>
<td>1.17 (0.83 – 1.65)</td>
</tr>
<tr>
<td>% Time lived in urban areas</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td>38%</td>
<td>42%</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>≥50% to &lt;100%</td>
<td>44%</td>
<td>41%</td>
<td>1.31 (1.12 – 1.53)</td>
<td>1.15 (0.98 – 1.35)</td>
</tr>
<tr>
<td>&gt;0 - 50%</td>
<td>9.5%</td>
<td>7.7%</td>
<td>1.58 (1.21 – 2.06)</td>
<td>1.45 (1.10 – 1.91)</td>
</tr>
<tr>
<td>0</td>
<td>8.1%</td>
<td>9.1%</td>
<td>1.27 (0.97 – 1.67)</td>
<td>1.28 (0.94 – 1.73)</td>
</tr>
</tbody>
</table>

*Adjusted for age and province
†Adjusted for age, province, length of career (total), race, relationship status, and time lived in urban areas
#Fully-adjusted estimates for covariates were comparable for all models; MODEL 6 results are shown here for simplicity

Models 1 through 4 in Table 5.2 considered exposure based only on the SUNJEM. Overall, 737 cases (45%) and 713 controls (42%) were ever exposed to solar UVR at work (ever had an outdoor job) (Table 5.2, Model 1). When low/moderate jobs were excluded from that number, 590 cases and 594 controls ever had a high category outdoor job (outside >75% of a typical workday) (Table 5.2, Model 2). In the adjusted models, both of these variables led to very slightly reduced risk of prostate cancer (OR 0.99 and 0.92, respectively), however the results were not statistically significant (95% CI included an OR of 1.00). In Model 3, the number of exposure years (years in any outdoor job) in quartiles ranging from 0 (never had an outdoor job) to 35+ outdoor job years showed a trend of decreasing prostate cancer risk with increasing exposure-years (test for trend, p=0.147). In Model 4, where only the number of exposure years in high category jobs were considered as exposed, this same trend occurs, with an OR of 0.74 (95%CI 0.55 – 0.99) for the highest quartile of exposure-years (test for trend, p=0.095).

Models 5 and 6 expand upon the SUNJEM by adding in cumulative measures of UVR exposure from the TOMS satellite data. Similarly to Models 3 and 4, Model 5 considers all outdoor jobs, and Model 6 considers just those jobs with high category exposure as assigned by SUNJEM. In Model 5, the general pattern of decreasing risk of prostate cancer with increasing exposure appears again, with an OR of 0.78 (0.6 – 1.0) in the highest category of exposure (≥523 SED-yrs). Interestingly, a small excess risk of prostate cancer is noted when comparing the two lowest exposure categories to those without any occupational exposure, though the 95% confidence intervals do contain 1.0. In Model 6, which only sums satellite-measured exposure values during periods of a high category outdoor job, the risk of prostate cancer is decreased for all exposure categories compared to those with no exposure, and the highest category (≥629 SED-years) has an OR for prostate cancer of 0.68 (95%CI 0.51 – 0.92).
5.4 Discussion

This study provides evidence that long-term occupational exposure to solar UVR is protective against prostate cancer. As the sensitivity of the exposure metric for UVR increased, so too did the strength of this relationship. It is also likely that some of the workers identified by SUNJEM as unexposed were misclassified due to their recreational exposure to the sun, however since this has the effect of biasing to the null, if anything the reduced risk of prostate cancer in the highest exposure group could be even lower. Much of the evidence in recent years points to a similar conclusion: more sunlight exposure leads to a lower risk of both prostate cancer diagnosis and death [161, 165, 167, 172, 173]. While the exact biological mechanism for this relationship is not known, it has long been presumed to be linked with vitamin D levels in the body, which is increased most effectively via endogenous production in the skin from sun exposure. Prostate cells do contain vitamin D receptors (VDRs) and enzymes necessary for vitamin D metabolism, and vitamin D metabolites have anti-proliferative influences on prostate cancer cell lines in vitro and in vivo [174]. It has also been noted that Japanese men have a rate of prostate cancer 10 times lower than American men, and they also have a diet much richer in fish oils, which are an excellent source of dietary vitamin D [155].

Since Models 3 through 6 all considered exposure metrics that are time-dependent, the healthy-worker effect is a primary concern in the interpretation of these results. Many outdoor jobs tend to be inherently more physically demanding than indoor work, and thus attract/require a healthier workforce. It is therefore possible that the relationship observed between long-term solar UVR exposure and reduced risk of prostate cancer could be explained by the fact that those workers who are able to hold an outdoor job for 35 years are simply healthier than those who did not. Firstly, this dataset is less prone to the healthy worker effect bias because a person had to have at least held a job for 5 years to have been included, so compared to a truly general population study that may contain many ill people, there is less difference because all of the subjects were able to work; in fact 90% of the subjects had career lengths of at least 30 years. In addition, length of career was included in the model to further adjust for potentially less healthy workers with shorter career lengths (length of career was correlated with age, but the Pearson correlation coefficient was small, at 0.32). To further examine this potential bias, several sensitivity analyses were also performed. Firstly, the dataset was limited to only those people who had long careers (35+ years and then 40+ years (results not shown)). The same pattern of decreasing prostate cancer risk with increasing occupational UVR exposure was observed, though the ORs were closer to the null (for 35+ years only model: OR 0.71, 95%CI 0.52 – 0.98 in the highest category of exposure using the exposure metric from Model 6; for 40+ years only model: OR 0.82, 95%CI 0.59 – 1.01). It was also noted that the most common long-term outdoor jobs were farmers and fisherman, and these groups might be either less likely to undergo cancer screening since they have little contact with health professionals in general [175], or more likely to have other unique lifestyle and job characteristics that could lower their risk outside of UVR exposure [176]. For this reason, the analysis was repeated without people who had these jobs as their most common profession, and the interpretation of the results again remained unchanged (increasing exposure leading to
decreasing prostate cancer risk). As another consideration, the variables for markers of good health available in this dataset (BMI, smoking behaviour, diet, and physical activity levels) were not significantly different between the cases and controls, which provides further evidence that there is an effect of long-term solar UVR exposure on prostate cancer risk.

Very few of the variables that were considered as potential confounders actually had any effect on the exposure-response relationship in this study. This was not a surprising finding, as the original work on this dataset by Villeneuve and colleagues did not find many significant relationships between most of the potential risk factors and prostate cancer case status [170]. In particular, physical activity and BMI did not have an effect on the relationship between exposure to solar UVR at work and prostate cancer risk, which was interesting as it was thought that at least part of the benefit of being a long-term outdoor worker would have been linked to physical activity levels and healthier weight. This, however, lends more credence to the solar UVR being protective for prostate cancer itself. None of the other occupational carcinogen exposures were important in the models, though the outdoor workers did report higher prevalence of exposure to both pesticides and asphalt fumes. The main limitations of this study are the lack of information on the severity of prostate cancer, as well as the lack of information on screening behaviours of the subjects. Autopsy studies have found that prevalence of prostate cancer in American Caucasian men over 50 was more than 40%, and this increased to over 80% by aged 80 [177]. Since we don’t know if the reason that prostate cancer was discovered was from routine screening or due to presentation of symptoms, cases in the present study might have been more likely to be screened than the controls for some reason that we could not detect. However, this was probably less likely to be true in the mid-1990s as it is now (when screening is more widely available). Several variables that are related to screening behaviour, including marital status, education, income, living in an urban area, and race/ethnicity were considered in the analysis, and in fact all of these except income and education remained important in the final models. Prostate cancer cases were more likely to be married or widowed than single, which suggests a screening effect (partners convincing participants to seek health care), and in general more educated and wealthier people had higher risk of prostate cancer (though these two variables did not maintain significance in the final models), which also suggests there could be a minor effect of increased screening among cases (educated and wealthier people tend to undergo screening for prostate cancer more often) [178]. However, people who lived more of their lives in rural areas were actually at higher risk of prostate cancer, when easier access to healthcare and screening is expected in urban areas. It is not entirely clear what could be behind this finding, but it may reflect underlying risk factors that differ by location. Questionnaires were not sent to cases that were deceased or known to have advanced disease, which is likely to have excluded those with aggressive and/or rapidly fatal disease. However, this would lead to an attenuation of risk estimates, since the case population were more likely to have similar risk profiles as the control population [170].

The sensitivity of the UVR exposure metric mattered for the association with prostate cancer. The strength of the association increased from the use of the more general measure of
ever/never had an outdoor job to the more discerning measure of time spent outdoors correcting for actual estimated available levels of UVR for each location throughout the life course. However, there is still the possibility of misclassification of exposure, particularly because leisure time sun behaviours could not be captured. Indeed, it is likely that some of the people counted as unexposed at work may have still had high sun exposure either in their leisure time or on vacation. Outdoor workers often actually spend more leisure time in the sun than indoor workers [40], so it is likely that the truly highly exposed people were captured in this exposure assessment. The yearly average UVR dose per location was used as a metric in this study, even though the maximum average monthly metric was also available. These two values were highly correlated across nearly all locations (except those in particularly sunny climates closer to the equator, which were very few in this population) so the more stable yearly average was selected to weight the outdoor occupational time. Indeed, this procedure was considered as a weighting for the JEM estimates, as it cannot be determined how much of the available UVR was actually absorbed by the outdoor workers. It would certainly not be the total available amount, so a categorical weighting was a more valid way to assess exposure that to consider it as a true dose.

This study adds to the growing literature suggesting that UVR exposure may lead to a decreased risk of prostate cancer. In particular, it addressed the need for the measurement of occupational exposure to solar UVR, and it allowed for a full occupational history to be coded for outdoor work and weighted to available UVR by address over the life course. People with the highest cumulative exposure to solar UVR at work gained the most benefit. This has important risk communication implications for sun protection in outdoor workers, because solar UVR is the leading cause of skin cancer and is a major concern for outdoor workers; moderation through sun protection behaviours/practices especially during peak or lengthy exposure periods may be the key to gain the most benefit from the sun, while mitigating risk of other known malignancies.
Chapter 6: Discussion

The work presented in this thesis addressed some of the knowledge gaps and challenges in the assessment of occupational solar ultraviolet radiation (UVR) exposure. The individual chapters focused on the development (and improvement of) a standardized JEM for outdoor work, the determinants of sun protection behaviours used by outdoor workers and how this information could be used to develop workplace policies for skin cancer prevention, the levels of UVR exposure in outdoor workers in the Canadian context, and the effect of cumulative UVR exposure on risk of prostate cancer using improved measurements.

6.1 Summary of the research and contribution to the literature

6.1.1 Chapter 2: SUNJEM study

Chapter 2, “Estimating population-level exposure to occupational solar ultraviolet radiation (UVR) in Canada”, framed the problem of sun exposure as an occupational hazard in Canada. Using a combination of data sources, the prevalence of outdoor work was estimated at approximately 1.5 million workers in Canada (9% of the total workforce), and around 900,000 of these were categorized as working outside for more than ¾ of their workdays (high exposure). These workers were largely male (>80%), reflecting the industries that tend to include more outdoor work (agriculture and construction).

Outdoor work also has a geographic component in Canada that is driven by both the economies of each province with respect to industrial breakdown, as well as the available solar UVR. In PEI, where farming represents a substantial proportion of the workforce, nearly 18% of workers are expected to have an outdoor component to their job. In Ontario and Quebec with the largest outdoor working populations due to their population size, the proportion of outdoor workers is much smaller due to a more diverse economy that includes the majority of manufacturing work in Canada. This geographical component is also important with respect to the available solar UVR, which is affected most strongly in Canada by latitude, but also by altitude and local climate. Interestingly, in all locations in Canada, risky UVR levels occur during at least some of the year; an SED of 2-3 can cause a sunburn in a very light-skinned individual (Skin Type I), and as the map of variability in UVR dose showed, even in Canada’s north, the mean ambient SED per day in the summer is around 30 SED.

The prevalence of exposure calculated in Chapter 2 was lower than the previous estimate of outdoor work in Canada. This was likely due to the increased specificity achieved by a detailed review of several sources of information quantifying outdoor work and applying expert assessment. The Second National Sun Survey (NSS2) reported that 5.9 million Canadians had a job that required them to work outdoors (in a specific reference year and season of summer 2006) [40]. However this estimate was based on self-reports with no quantification of time spent outdoors. As a result, workers with minimal time spent outside at work could be categorized as exposed. The prevalence of exposure in the current study (ranging from 5% for
those in the high category of exposure to 9% for all workers with potential exposure) is much more in line with prevalence estimates from Great Britain (a country of similar latitude and comparable solar UVR levels) of about 7% of the working population working outdoors [99].

A job exposure matrix (SUNJEM) for outdoor work in the Canadian context was also created as part of the research in Chapter 2, providing a substantial resource for future epidemiological studies and research methods. Exposure assessment of occupational carcinogens is often hampered by a lack of exposure data, but this is perhaps even more of a challenge in solar UVR exposure assessment, where very few countries in the world have any kind of systematic exposure monitoring program. For this reason, JEMs are a critical tool in occupational studies of solar UVR, and the SUNJEM can be used in epidemiologic studies of skin cancer (with or without information on location), as well as any of the other diseases that are known or suspected of being linked with solar UVR exposure (e.g. bone health, rheumatoid arthritis, diabetes, prostate and other cancers).

6.1.2 Chapter 3: sun protection study

In Chapter 3, “Sun protection behaviours among outdoor workers in British Columbia, Canada”, the determining factors for sun protection behaviours used by workers were examined in the context of the Outdoor Workers Project. The study contributes to the literature on sun protection behaviours in outdoor workers in particular because it focused on a high-risk industry that included mostly men (the group at highest risk of skin cancer).

A strong relationship was seen between having a lighter Fitzpatrick skin type and a higher sun protection score both at work and at leisure (when the protection score is a mean score, ranging from 0 to 4, calculated from Likert-scale answers to questions on sunscreen use, seeking shade, and wearing a hat, shirt, and sunglasses). The lighter their skin tone (i.e. the higher the risk of sunburn and skin cancer), the more protective behaviours a worker tended to practice. In this group of 77 workers, in fact, no other factor reached statistical significance in predictive models for worktime sun protection score. However, an interesting relationship between job type was noted, in that those working in primarily construction-based jobs had higher sun protection scores than those in horticulture, and this was driven by the type of personal protective equipment that construction sites usually require (hard hats and long sleeved shirts). In this way, a site-level policy or a workers’ compensation regulation for safety reasons led to sun protection being worn inadvertently.

Occupational settings represent a difficult setting to enact skin cancer prevention policies. The guidelines for skin cancer prevention at a population level involve some combination of sun avoidance (especially at peak times), covering up, and wearing sunscreen [107]. Outdoor workers have no choice about when their work takes place, and peak times in Canada are roughly 11am to 3pm (depending on location), right in the middle of the most common work shifts. In addition, outdoor workers are often a unique population who tend also to spend more time in the sun outside of work [40, 111], and stay in their careers for much longer than average [110, 179]. Therefore, they are at the highest risk of skin cancer in the general
population, after controlling for skin type and the small protection factor offered by repeated exposure. Covering up as a workplace safety practice could be useful, as observed in the Outdoor Workers Project. However, the clothing choice is important as it needs to balance the other needs of the workers with respect to safety and comfort (especially as it pertains to heat stress).

6.1.3 Chapter 4: UVR exposure level study

The study of personal monitoring for levels of UVR exposure in the Outdoor Workers Project, presented in Chapter 4, provides a useful addition to the literature of limited studies from around the world that have measured UVR exposure, rather than estimated it by proxy. In particular, including a substantial number of construction workers and monitoring over five exposed days created a dataset that could be used for exposure estimation for workers in similar locations and working circumstances.

The exposure monitoring results showed high variability between workers, and a lognormal distribution of the measures. In addition, the mean exposure levels (corrected for repeated measurements) were approximately 1 SED per day, which is well above the ACGIH exposure guideline of 0.3 SED (or 30 J/m²). A comparison of how the UV Index relates to times to exceed the exposure guideline, times to get a sunburn, and the equivalent SEDs per hour is shown in Table 6.1. At typical UV Index values recorded during the Outdoor Workers Project (6 – 8), workers would exceed the exposure guideline in just 10 to 13 minutes. This shows that even on the west coast of Canada, a location better known for rain showers than risky sun exposure, solar UVR is still an important exposure consideration in outdoor workers.

Table 6.1 UV Index and influences on time to exceed the exposure guidelines, time to achieve sunburn, and the equivalent SEDs per hour (adapted from Gies et al. 2009) [130]

<table>
<thead>
<tr>
<th>UV Index</th>
<th>Time to exceed TLV (minutes)</th>
<th>Time to achieve erythema (min)</th>
<th>Ambient UVR (SEDs/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>26</td>
<td>44</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>33</td>
<td>4</td>
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<td>6</td>
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<td>22</td>
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<td>10</td>
<td>17</td>
<td>7</td>
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<td>10</td>
<td>8</td>
<td>13</td>
<td>9</td>
</tr>
</tbody>
</table>

The study also demonstrated feasibility of dosimetry with limited researcher contact and of interest for occupational exposure assessment in research. Workers were largely compliant with wearing the dosimetry badge each day of the study, and the monitors chosen were robust and the time-stamped nature of the measurements is very useful for integrating accurate exposure metrics over exposure days. Dosimetry for solar UVR in outdoor workers has no gold standard, and often researchers manufacture their own dosimeters in research labs (polysulphone badges), which may lead to a lack of standardization across studies and reduced
comparability of the resultant measurements. A move to use more physically robust monitors that allow for detailed measurements has increased the desirability of an electronic dosimeter, and the Mark II badges used in the Outdoor Workers Project are now available commercially, and with increased use, the cost should come down.

6.1.4 Chapter 5: protective effect for prostate cancer study

The analyses included in Chapter 5 ("Solar ultraviolet radiation exposure and prostate cancer: Reduced risk after long-term exposure") added evidence to the growing literature suggesting that solar UVR exposure may have a protective effect against prostate cancer. In particular, among men with high cumulative exposure, the odds of a prostate cancer diagnosis was 0.70 (for the most refined measure of high occupational exposure). The addition of more studies with increasingly detailed exposure assessment to the literature is necessary, as several studies have found no clear effect of solar UVR exposure [180, 181], or even a negative effect at high exposure levels [182].

The NECSS study was an appropriate dataset to test the hypothesis that solar UVR exposure at work in particular reduces prostate cancer risk. Full occupational histories were available for all study subjects (with some minimal missing data), so exposure in all outdoor jobs held for at least one year could be accounted for in the exposure metrics (not just usual job, or job at death or diagnosis). There were over 1,600 cases and controls available for study, a large dataset for epidemiological analyses.

The identification of potentially modifiable risk factors for prostate cancer is an important quest. Prostate cancer is the second leading cause of cancer in Canadian men (second only to skin cancer), and yet the only causal factors that have been identified are advanced age, family history of prostate cancer, racial background, and screening behaviours [183]. Exposure to solar UVR (at least at moderate levels to achieve a reasonable trade-off with skin cancer risk), or perhaps supplementation with vitamin D are reasonable modifications to behaviour that could be achieved at a population level and have positive implications for public health, including and beyond the outdoor working population.

6.2 Strengths and limitations: methodological considerations

6.2.1 SUNJEM study

Job exposure matrices (JEMs) have experienced a long history of methodological developments, and the idea that the aggregation of job and exposure information is both advantageous as well as detrimental (with respect to the exposure misclassification it creates) is well-known [184]. The risk of non-differential exposure misclassification that leads to a reduced ability to detect an effect where one exists (e.g. biasing odds ratios to the null), should not be overlooked when using a JEM for exposure assessment [185].
The SUNJEM must be used with the knowledge that the levels of exposure are of relative quality, rather than conveying any information on actual exposure-related values or risk. The levels were assigned in the JEM using an Australian framework for identifying outdoor workers, and the exposure level differences between Australia and Canada are quite large. However, the jobs identified as exposed in Australia are very likely to be exposed in Canada as well, especially if the marker of exposure is having a job that is at least sometimes outside. Certainly some jobs in Australia are more likely to be outdoors year-round, while some jobs in Canada are more likely to be outdoors seasonally. However, in a qualitative sense, the jobs identified as highly exposed in SUNJEM are also likely to be highly exposed in Australia.

The majority of studies of UVR exposure in occupational settings use self-reported outdoor work (ever/never or yes/no), sometimes with the added detail of the amount of time spent outdoors on a typical workday [70]. In studies that relied on a JEM, several have used FINJEM, as it has a component on UVR exposure [59, 186-188]. Other studies have used their own JEM for UV radiation; a French JEM for sun exposure was developed for use in a variety of studies that includes estimates of proportion of workers exposed, and qualitative estimates of exposure frequency and UVR intensity, scored as a product [60, 61]. European JEMs (including the original CAREX EU projects) were useful starting points for SUNJEM, but the coding structures in Europe tend to be less detailed than the structures typically used in North America. In addition, recoding from one coding system to another (especially where the new system is more detailed) can cause agreement issues. In an analysis of these agreement issues, Kromhout and Vermeulen showed that for dissimilar coding structures, the agreement in coding was just 49% [189]. Therefore, the SUNJEM was an important addition to the literature and could easily be used in studies with detailed coding structures for occupational and industry.

### 6.2.2 Sun protection study

One of the limitations of the sun protection behaviours study within the Outdoor Workers Project was the lack of information on workers’ beliefs surrounding sun protection and risk of skin cancer, and of perceptions of workplace support or culture. These items were not a main objective of the study as a whole, so they were not included in the interest of time to fill out the questionnaire, but this information would have provided more context to the responses on protection and why it was used. In general, and even in high exposure countries like New Zealand and Australia, the attitude of outdoor workers towards sun protection is one of nonchalance [68, 111], and any effort to enact skin cancer prevention policies in workplaces must take this into account. This could be of particular significance in Canada, where we do not have any data on belief systems about UVR exposure prevention in outdoor workers and there is a legitimately lower risk of skin cancer to outdoor workers here than in Australia. In addition, because a difference was noted between the type of workplace and sun protection scores that was due to workplace requirements, it would have been interesting to know if workers saw this as a positive, added benefit of their workplace and safety policies.
Another methodological challenge noted in Chapter 3 was the homogenous study group (mostly from one industry, mostly male, and mostly from a few large employers), which made it difficult to detect any significant predictors of the sun protection scores beyond the most obvious risk factor for skin cancer (lighter skin type). Examining the construction industry was done purposely, as it is a large and high-risk industry for sun exposure in Canada [132], however future studies of sun protection in outdoor workers in Canada would do better to recruit participants from a wider variety of workplace sizes and types, even within construction and to include more women where possible. The Outdoor Workers Project study was primarily designed to generate evidence of UVR exposure in outdoor workers in the Canadian context, and to begin to understand sun protection behaviour, among a high-risk occupational group. We were interested in examining sun protection behaviors in the Outdoor Workers Project because it was hoped that the data would give clues about how best to target skin cancer prevention resources in Canadian workplaces. A more diverse set of participants in future studies will provide additional evidence for targeting other occupations or industries, should differences emerge in exposure levels and protection practices/behaviours. The inclusion of women in future occupational studies will also help with targeting recommendations given there are known gendered- and sexed differences in sun protection and skin cancer prevention in the general population that may or may not persist in the workplace setting [68, 128]. However, workplace requirements for a hard hat and long sleeved shirt did appear to influence sun protective behaviours in the Outdoor Workers Project, and this is a useful piece of information for policy makers in skin cancer prevention regardless of gender/sex.

A strength of Chapter 3 was the ability to compare how workers protected themselves from the sun at work and at leisure. Most intriguing was that sun protection scores on weekends were lower than on workdays (though this may have partially reflect the amount of time spent in the sun in different circumstances), but also that workers are three times more likely to seek shade on the weekends than at work. Indeed, this reflects more limited opportunities to seek shade while on the job and performing work tasks, but suggests that workers might use shaded areas or portable structures at work if they were available. In addition, workers who said they purposely tanned their skin were much less likely to protect themselves from the sun, which is an unsurprising result. However, this could represent a group that could be targeted for extra education on the harmful effects of solar UVR exposure.

It is imperative in any discussion of the workplace use of personal protective equipment (PPE) to stress that it should always be the last line of defense for workers, as per the hierarchy of controls. Industrial hygiene tenets (here adopted for UVR exposure reduction) are founded on the principle that removing the hazard altogether (eliminating or substituting), using engineering solutions (e.g. shade structures), or enacting administrative controls (e.g. limiting outdoor work at or near solar noon) should all be considered before PPE use (sunscreen, wearing hats, etc.) Since the responsibility for sun protection at work remains that of the workers themselves in Canada at present, effecting large-scale change in practices will be difficult. Moving up the hierarchy to include workplaces and regulators in the enactment of prevention practices would be more impactful at a population-level [190]. Regulators such as
workers’ compensation systems may have a key role to play in encouraging broad-based protection practices; and unions a key role to play in raising awareness of the risk of the working environment for outdoor workers and to advocate for regulatory changes.

6.2.3 UVR exposure level study

The methodological considerations for measuring personal exposure to solar UVR in epidemiological studies are numerous, and these issues are compounded when considering their use in outdoor working populations. There are three basic types of tools for physically measuring UVR exposure in individuals: chemical, biological, and physical sensors.

Chemical methods involve the measurement of a chemical change produced by UVR, and the polysulphone (PS) are the most commonly used dosimeter in studies of personal exposure [191]. The principle of the method is that PS film absorbs UV radiation, and an increase in absorbance at 330nm occurs with increasing UV dose. The PS film is mounted on cardboard or plastic, or can be worn directly on the skin in some cases. Although PS has been the most widely used type of personal dosimeter, it has some distinct challenges that have been leading researchers and engineers to other solutions. PS film methods do not clearly distinguish between UV-A and UV-B exposure, which may be of importance in some studies. There is a high cost to using PS. The film itself is inexpensive, but it is typically made by individual researchers in labs as there is not a good commercial source, so the start-up costs are high. The film can also easily saturate and must be kept in complete absence of UV light whenever not in use.

Biological methods are less common, but normally involve the measurement of time to mutation induction in microorganisms (typically bacteria). They too provide reproducible measures of exposure and are easy to wear, but require a lot of expensive planning (similar to PS), and they need to be replaced throughout the day, which can lead to exposure measurement errors and hassle or even impracticability in working environments.

Physical methods use photodiode sensors (of varying types) to measure UV. In the Outdoor Workers Project, the Mark II sensors were used, and these employ an aluminum-gallium-nitride (AlGaN) photodiode, which has a spectral response that closely matches the CIE Erythemal Action Spectrum [71]. The sensor converts UVR into a small electrical current, and because the current is so small, the processor accumulates the UVR measures over time (normally a fraction of a second) before recording a value. This integration time is key because it means the Mark IIs can be adjusted for varying intensity of UVR. The badges are small and lightweight and easy to use and administer by research subjects (lessening the need for researcher intervention). They also can sample up to once per second and so exposure at different points in the day can be examined, and there are no saturation issues. The drawbacks of an electronic dosimeter is that they can be expensive (however they are reusable, unlike chemical or biological sensors), and their design and use is not yet standardized, especially as they compare and contrast to PS badges; this makes comparisons between different studies and their exposure metrics more difficult.
The Mark II dosimeters were selected for use in this study primarily because they were commercially available, programmable for ease of subjects’ use (the field study was carried out by one person only, so this was important), allowed the ability to examine exposure at different time periods, and were reusable. In general, the dosimeters performed well. There were only 4 worker-measurement days of data lost (out of 341 worker-days measured in total or 1.2%), and they all occurred with one subject; a further 23 worker-days were deemed ‘idle’ where it was likely that a worker did not wear their badge (6.7%). Overall compliance with donning the badge was deemed relatively high, which was important in a study that was subject-directed. These data and observations provide evidence that electronic dosimeters like the Mark II would be useful to consider for use in other occupational exposure studies, and this would provide more measured exposure level data to compare to.

There were, however, several instances during the course of the sampling where badges were covered up partially by clothing, or flipping to point downward rather than straight out from the lapel. This was corrected by the researcher when observed, but further instructions with reminders should be provided to participants to reduce this measurement issue. As a result, it is likely that the mean exposure values measured in the Outdoor Workers Project were underestimates, and that the problem of solar UVR exposure on Canada’s west coast could be somewhat larger.

A secondary challenge that was faced was the poor quality of data collected from the task diaries, intended to provide work-related or task-related determinants of exposure variables. In a majority of the cases, the same posture, shade availability, clothing choice, and tasks were filled out for entire workdays, and indeed entire work weeks. This hindered the ability to examine task-based determinants of different exposure levels within and between workers in the Outdoor Workers Project. In future studies (perhaps particularly in construction workers), it would be beneficial to have more observation of tasks by researchers (either in person or via video recordings), or more time allotted by employers for workers to fill out their diaries as they work, rather than once at the end of the day (or even once at the end of five days).

Broad calls for an increase in personal dosimetry, particularly for outdoor workers for which data is quite sparse, have been made in recent years [3]. This has been driven by the observation that large within-population variations in exposure exist in the same location (i.e. with the same ambient UVR), which indicates that personal behaviour is an important driver of UVR exposure [192]. In a Danish study where many UVR dosimetry studies have been carried out, even indoor workers in the same city had yearly SED values ranging from 17 to 841 SED/year [147]. Even though personal dosimetry may not be feasible for large population-based studies, in order to create accurate models of exposure or to develop methods that accurately predict exposure measures, personal measures are required to supplement or adjust the available ambient measures of UVR. Dadvand and colleagues showed that within-city variability in UVR exposure is higher than between-city variability, and that using ambient models with UVR level and latitude alone will result in a significant loss of statistical power to detect associations between UVR and human health [192]. Summertime-only exposure data was
collected in this study because this is the time of year in Canada where risk of sunburn is highest, and thus is the time when skin cancer prevention work often takes place. Indeed, in the Canadian winter, UVR exposure is too low to even allow the endogenous production of vitamin D, leading physicians to recommend supplementation in the diet [193]. Since Canadian winters are cold, workers are also likely to be more covered up, and the daylight hours are shorter. A significant contribution to the UVR dosimetry literature could be made by considering year-round exposure in Canadian outdoor working populations, with a special consideration of the potential for exposure in mountain/snow-covered environments.

6.2.4 Protective effect for prostate cancer study

The main strength of Chapter 5, “Solar ultraviolet radiation exposure and prostate cancer: Reduced risk after long-term exposure”, was the application of a new job exposure matrix (JEM) for outdoor work based on time spent outdoors per work day, adjusted for ambient UVR available throughout the working life. Studies of UVR exposure and reduced risk of prostate cancer have been done before, but the majority of studies have focused on residential exposure. The few that have addressed occupational exposure to solar UVR have been of varying quality for the exposure assessment. For example, in a study by John et al. using the NHANES I data (National Health and Nutrition Examination Survey), occupational UVR exposure was assessed by self-report of never/rare, occasional, or frequent exposure [194]. In a study of prostate cancer mortality, usual occupation on the death certificate was coded by an industrial hygienist as indoor, combination indoor/outdoor, farming, or outdoor non-farming [64]. In neither of the previous studies was a significant relationship with occupational exposure and prostate cancer outcome detected. In another study by John and colleagues, exposure to outdoor work was estimated by researchers using data from occupational histories and in hours per week over the lifetime, and a protective effect observed (though not significant) for those with the highest number of hours per week working outdoors [195]. Increasing the specificity of the exposure assessment via the SUNJEM and the satellite enhancements may have led to the ability to detect significant relationships with high cumulative exposure to solar UVR at work and reduced prostate cancer odds.

A large portion of Chapter 5 was devoted to a discussion of the healthy worker effect and how it may have affected the results of this study. Since outdoor jobs tend to require a certain degree of physical resiliency that is required less of indoor work, the simple fact of being able to have an outdoor job, and have one for a long time, could be a source of bias in these results. However, as was noted in the Discussion of Chapter 5, the dataset used was less prone to this issue because all of the included people were employed for at least part of their lives, and 90% of them had careers of at least 30 years. Physical activity, obesity, and dietary considerations were also not important in the final models, and these are three of the primary ways in which the healthy worker effect may operate. Cancer incidence is also normally affected by the healthy worker effect to a lesser degree because it is unlikely that the risk factors for cancer would have been present when a person was first deciding on employment [196]. In addition,
Prostate cancer in particular is a cancer of older age, and the healthy worker effect normally diminishes as the age of the cohort increases [197].

A primary methodological limitation of the study of prostate cancer risk was the lack of information on screening practices. Prostate cancer becomes increasingly prevalent as men age, though it can either be latent or more severe requiring treatment. It is possible that the people who were diagnosed with prostate cancer in the NECSS were simply more likely to have been screened than the controls [34]. However, several considerations suggest that this effect might be diminished in this particular dataset. Firstly, the NECSS took place in the mid-1990s, when PSA (prostate-specific antigen) screening testing was still relatively new and evidence to suggest screening was appropriate was not necessarily available [198]. Secondly, we were able to investigate and control for the effect of several variables that are correlated with screening practices (e.g. relationship status, residential location, education, income, and racial background). Therefore, while screening behaviours cannot completely be ruled out as a bias affecting our results, these considerations at least lessen this concern.

Ultraviolet radiation is not constant over time. Since the late 1970s, the average ultraviolet irradiance has increased everywhere except near the equator, though the increase has stabilized since the late 1990s (likely due to the decreased use of chlorofluorocarbons and subsequent repair of the ozone layer) [199]. However, especially in the northern hemisphere, these changes have been relatively minor (4% at 50°N, for example) and are not likely to have a strong impact on the exposure estimates used in Chapter 5.

6.3 Validity in exposure assessment

A formal evaluation of the validity of SUNJEM was not possible in the course of this work due to time and budget constraints, but the procedures used were consistent with established methods for developing job exposure matrices. Validity could be assessed in future by selecting sets of jobs in each exposure level category (i.e. not exposed, and low, moderate and high exposure) and measuring groups of workers’ exposure over some pre-determined time frame. These measures could be compared to ensure that the levels were a meaningful representation of true exposure in a working population, and adjustments could be made to SUNJEM where the initial assessment was deemed incorrect. This would have the desirable effect of reducing exposure misclassification (an issue inherent to the expert-driven assessment of exposure at a population level), and potentially increasing the effect size away from the null if a true relationship exists [200]. However, the use of SUNJEM to evaluate exposure in Chapter 5 did allow the detection of a decreased risk of prostate cancer with increasing exposure, which was the hypothesis being tested; this shows that SUNJEM has face validity. In addition, SUNJEM would have correctly assigned relative UVR exposure for the workers that were evaluated for their personal exposures in Chapter 4 (e.g. paving workers in the high exposure category, construction foremen in the moderate category, and wildlife protection workers in the low category), again indicating strong face validity. This body of work represented a foyer into a new field in exposure assessment, and improvements in the standardization of measurement
techniques, as well as the use and refinement of SUNJEM in other studies will contribute to a better understanding of its validity as a tool for exposure assessment more broadly.

6.4 Recommendations for future research

The results from this thesis lead to a variety of observations on further research. This is at least partly driven by the lack of standardization of the measurement of solar UVR in both occupational and residential settings, as well as by the intriguing implications of both positive and negative health effects of solar UVR exposure in humans.

Firstly, the lack of personal dosimetry in all but a few countries and occupations around the world represents a significant challenge with respect to accurate assessment of exposures for UVR-related health outcomes in research studies. Vernez and colleagues have made great strides in exposure modelling for solar using the SimUVEx (simulating UV exposure) model, which predicts the dose and anatomical distribution of UVR exposure using morphological data and ground irradiance measurements \[201\]. This model predicted exposure with a similar degree of accuracy to polysulphone badges (error of approximately 10-13\%). However, the authors report that the model works best on consistently cloud-free days in a person who is consistently outdoors with predictable body posture information. Significant errors occur when a worker moves in and out of shaded environments, when there are cloudy periods, and in snow-covered environments. More exposure data collection from a variety of different workers in different situations, with a validation component would be very useful to improve models like SimUVEx \[201\]. A more fulsome understanding of the determinants of exposure in outdoor working populations should also be a goal of further exposure monitoring studies. Advances in UVR dosimetry and secondary data collection (i.e. development of new and cheaper monitors, different tools to capture sun protection behaviours via smart phones) could make these advancements happen more quickly and on a population-based, broader scale.

Some might argue that the collection of exposure data for a hazard that is a known cause of cancer is not a good use of finite resources. However, the problem with solar UVR exposure is that the dose-response relationship with skin cancer is poorly understood. The pattern of exposure seems to be important for skin cancer type, with long-term cumulative exposure being important for SCC and to a lesser extent BCC, and early life and intermittent acute exposure being important for BCC and melanoma \[24\]. However, in a meta-analysis of the risk of SCC (squamous cell carcinoma) due to occupational UVR exposure, the authors reported that the crude exposure assessments in the available studies (i.e. the reference group being defined as “mainly indoor work”, a group that very likely includes people with significant exposure) has led to non-differential misclassification and an underestimate of the true effect of solar UVR on skin cancer risk \[202\]. Indeed for BCC, it has only recently become accepted (since 2011) that it is linked to occupational exposure, and it appears that this is largely due to improving exposure assessment over time allowing the detection of the risk \[27\]. Further research is needed to discern why it is that melanoma does not appear to be linked to occupational exposure – is it a
problem of poor exposure assessment, or are there other factors at play? Improved measurement for occupational and leisure time exposure would add more precision to epidemiologic studies of skin cancer, and knowledge of the dose-response relationship is key to targeting prevention messaging in at-risk populations. Skin cancer epidemiology would also be improved by efforts to collect better data on non-melanoma skin cancer (NMSC). Many jurisdictions worldwide do not collect incidence data on NMSC in cancer registries and this hampers efforts to identify relevant risk factors in occupational research or to develop prevention strategies for workers.

A second problem with solar UVR exposure assessment is that at least in Canada (and indeed, probably most countries outside of Australia or New Zealand), occupational sun exposure is not understood to be a significant risk factor (there are no exposure levels specifically for solar UVR exposure in any Canadian provinces, for example. General protections for sun exposure are sometimes included, but focus on awareness and personal protective equipment use). This is despite clear evidence from this thesis and a large body of previous scientific work that shows levels of exposure associated with sunburn, lifetime high levels of UVR exposure, and known linkages with occupational skin cancer. More work in this area of research is needed to inform policies and regulations to protect workers from known hazardous exposures.

Effective skin cancer prevention strategies in workplace settings have so far been lacklustre in terms of effectiveness, until recently [203]. In 2013, recent evidence indicated that tailored interventions are effective in different groups, specifically men and women. Gender is strongly associated with sun protective behaviour and men and women may respond differently to intervention resources. Gender is also an important consideration in intervention design as the jobs at risk of high occupational UVR exposure (e.g. construction, farming, and logging) tend to have more male workforces, in addition to more “macho” and less protective cultures [128]. Addressing these challenges could lead to strides in effective interventions in young, male workplaces, not just for skin cancer prevention, but any number of workplace hazards.

It would be a useful exercise to compare and contrast the few JEMs that have been developed to address occupational solar UVR exposure in population-based studies, such as FINJEM, or other ones created ad hoc for varying studies. If a registry of JEMs were available to researchers, this could lead to important findings on potential biases in the JEMs, as well as considerations of how outdoor jobs may (or may not) differ based on country.

Clearly, more research needs to be done into the natural history of prostate cancer, and with particular focus on the potential risk factors. Prostate cancer is a significant public health issue in men, and a clearer understanding of its etiology is key to address modifiable factors in its development. The results in this thesis suggest that occupational solar UVR exposure could have a protective effect for prostate cancer, especially when the exposure is higher in level and/or length of time. These results should be interpreted with caution, and certainly need to be replicated in other studies using detailed exposure UVR exposure assessment, preferably including data on leisure time exposures as well. However, if the relationship is indeed true, some interesting implications arise for cancer prevention messaging. A balance must be struck
with the prevention of skin cancer and prostate cancer (and other known and suspected vitamin D-relevant health outcomes). However, the amount of sun required to produce an adequate amount of vitamin D is actually very little depending on geographic location and skin type (among other things). For example, among a person with skin type II at approximately 42° North latitude in June at noon, only about 5 to 15 minutes of exposure to the arms and legs, three times per week is ample to produce enough vitamin D to prevent health effects [19], and should keep the risk of skin cancer relatively low.

6.5 Summary

The purpose of this thesis was to address knowledge gaps in exposure assessment for solar ultraviolet radiation (UVR) in outdoor workers. To that end, a job exposure matrix was created and further enhanced by the use of ambient UVR data over the working life. In addition, potentially harmful exposure levels were measured in outdoor workers in Vancouver, a Canadian city more known for clouds and rain than for harmful UVR exposure. Individual risk factors (skin type) were found to be more important in driving outdoor workers’ sun protection practices, but an effect of workplace clothing requirements was also found. And finally, outdoor workers with the highest cumulative exposure to solar UVR at work had a decreased risk of prostate cancer, providing further evidence that the sun has both positive and negative effects on human health.
References


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Appendices

Appendix A  Copy of the questionnaire used in the Outdoor Workers Project

Date:    /   /  
Day        Month       Year

FOR RESEARCHER USE ONLY
Dosimeter ID:       Location ID:

UBC Outdoor Workers Project Questionnaire

This questionnaire has 4 sections. In Section 1, we will gather information on your sun habits, both when you are at work and on your leisure time. Section 2 asks questions about personal characteristics that may be associated with skin cancer risk, such as skin and hair colour. Section 3 will gather information on your job, and Section 4 asks some demographic questions. All information provided to us is confidential and will not be released to another party without permission. If there are any questions that you are not comfortable answering, you do not have to answer them.

For each question listed, please select the one answer that is the best response to the question. Fill in each circle or mark with a tick. ✓ Return completed surveys to . You can also speak to Cheryl on site if you need clarification on any of the questions.

Section 1: Sun Habits

1. In the summer, on average, how many hours are you outside per day between 10 AM and 4 PM., on days when you are AT WORK?
   1 hour or less................................................................. O
   2 hours.................................................................. O
   3 hours ................................................................. O
   4 hours.................................................................. O
   5 hours.................................................................. O
   6 hours.................................................................. O

2. In the summer, on average, how many hours are you outside per day between 10 AM and 4 PM.. on days when you are NOT AT WORK?
   1 hour or less................................................................. O
   2 hours.................................................................. O
   3 hours ................................................................. O
   4 hours.................................................................. O
   5 hours.................................................................. O
   6 hours.................................................................. O
3. How often do you spend time in the sun in order to get a tan?

<table>
<thead>
<tr>
<th></th>
<th>NEVER</th>
<th>RARELY</th>
<th>SOMETIMES</th>
<th>OFTEN</th>
<th>ALWAYS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

4. How many times LAST SUMMER did you have a red OR painful sunburn that lasted a day or more?
(Circle one response)

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5+</th>
</tr>
</thead>
</table>

For the following questions, think about what you do when you are outside AT WORK during the summer on a warm sunny day.

5. How often do you wear SUNSCREEN?

<table>
<thead>
<tr>
<th></th>
<th>NEVER</th>
<th>RARELY</th>
<th>SOMETIMES</th>
<th>OFTEN</th>
<th>ALWAYS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

6. How often do you wear a SHIRT WITH SLEEVES that cover your shoulders?

<table>
<thead>
<tr>
<th></th>
<th>NEVER</th>
<th>RARELY</th>
<th>SOMETIMES</th>
<th>OFTEN</th>
<th>ALWAYS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

7. How often do you wear a HAT?

<table>
<thead>
<tr>
<th></th>
<th>NEVER</th>
<th>RARELY</th>
<th>SOMETIMES</th>
<th>OFTEN</th>
<th>ALWAYS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

8. How often do you stay in the SHADE or UNDER AN UMBRELLA?

<table>
<thead>
<tr>
<th></th>
<th>NEVER</th>
<th>RARELY</th>
<th>SOMETIMES</th>
<th>OFTEN</th>
<th>ALWAYS</th>
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<tr>
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<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

9. How often do you wear SUNGLASSES?

<table>
<thead>
<tr>
<th></th>
<th>NEVER</th>
<th>RARELY</th>
<th>SOMETIMES</th>
<th>OFTEN</th>
<th>ALWAYS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

For the following questions, think about what you do when you are outside and NOT AT WORK during the summer on a warm sunny day.

10. How often do you wear SUNSCREEN?

<table>
<thead>
<tr>
<th></th>
<th>NEVER</th>
<th>RARELY</th>
<th>SOMETIMES</th>
<th>OFTEN</th>
<th>ALWAYS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

11. How often do you wear a SHIRT WITH SLEEVES that cover your shoulders?

<table>
<thead>
<tr>
<th></th>
<th>NEVER</th>
<th>RARELY</th>
<th>SOMETIMES</th>
<th>OFTEN</th>
<th>ALWAYS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

12. How often do you wear a HAT?

<table>
<thead>
<tr>
<th></th>
<th>NEVER</th>
<th>RARELY</th>
<th>SOMETIMES</th>
<th>OFTEN</th>
<th>ALWAYS</th>
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<tr>
<td></td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

13. How often do you stay in the SHADE or UNDER AN UMBRELLA?

<table>
<thead>
<tr>
<th></th>
<th>NEVER</th>
<th>RARELY</th>
<th>SOMETIMES</th>
<th>OFTEN</th>
<th>ALWAYS</th>
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<td>O</td>
<td>O</td>
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</tr>
</tbody>
</table>

14. How often do you wear SUNGLASSES?

<table>
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<th>NEVER</th>
<th>RARELY</th>
<th>SOMETIMES</th>
<th>OFTEN</th>
<th>ALWAYS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

Section 2: Personal characteristics

15. What is your natural hair colour? If grey, what colour was it before it turned grey?

<table>
<thead>
<tr>
<th></th>
<th>Red or light blonde</th>
<th>Blonde</th>
<th>Dark blonde or light brown</th>
<th>Dark brown</th>
<th>Black</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

16. What is the colour of your eyes?

<table>
<thead>
<tr>
<th></th>
<th>Light blue, light grey, or light green</th>
<th>Blue, grey, or green</th>
<th>Hazel or light brown</th>
<th>Dark brown</th>
<th>Brownish black</th>
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<tbody>
<tr>
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<td>O</td>
<td>O</td>
<td>O</td>
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</table>

17. Which of the following skin colours best characterize you?:
Skin colour is light, pale white (Always burns, never tans) ...........................................O
Skin colour is fair (Usually burns, tans with difficulty) ..................................................O
Skin colour is white to olive (Sometimes develops a mild burn, gradually tan) .............O
Skin colour is olive to moderate brown (Rarely burns, tans with ease) .........................O
Skin colour is brown to dark brown (Very rarely burns, tans very easily) .....................O
Skin colour is very dark brown to black (Never burns, tans very easily) ......................O

18. As a child, did you have more than one severe sunburn? (i.e. painful and/or blistering)
   O No  O Yes

19. Have you ever been told by your doctor that you have skin cancer?
   O No  O Yes  O Don’t know  If YES, what type? (e.g. melanoma, squamous cell, basal cell carcinoma. Leave blank if unknown.)

20. Has anyone in your IMMEDIATE family (mother, father, sister, brother, child) been told by a doctor that they have skin cancer?
   O No  O Yes  O Don’t know  If YES, what type? (e.g. melanoma, squamous cell, basal cell carcinoma. Leave blank if unknown.)

21. Do you have a skin condition that worsens with sunlight exposure?
   O No  O Yes  O Don’t know  If YES, what type (e.g. photosensitivity, ‘allergy’)?

22. Have you ever worked with creosote before?
   O No  O Yes  O Don’t know  If YES, for approximately how many years?

Section 3: Job information

23. What is your CURRENT job title or trade?

24. What are your main job tasks? (for example “welding” or “operating an excavator”)

________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
25. How long have you been working in your CURRENT job or trade?  
________________________ years

26. Would you describe your typical CURRENT job/trade schedule as:

- <30 hours/week  
- 30-40 hours/week  
- 40-50 hours/week  
- >50 hours/week

27. Is your current job the job or trade you have held the longest?  
O No  O Yes  
(If YES, then skip to question 29 in SECTION 4)

28. If you answered NO to question #27, what has been your USUAL occupation or job -- the one you have worked at the longest?  
Job title ____________________________________________

Number of years employed in this LONGEST (or usual) occupation ________________

Main job tasks at your LONGEST job (i.e. waiting tables, installing cabinets, pouring concrete)

________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________

# of hours in SUMMER spent outside between 10am and 4pm at your LONGEST job: ______

Section 4: Background Information

29. Your sex:  
O Male  O Female

30. Date of birth: [ ] / [ ] / [ ]

Day  Month  Year

31. Racial/ethnic background: (Fill in one best choice)  
O Caucasian/White  O Asian  
O Black  O Other __________________
O Hispanic

32. What is the highest certificate, diploma or degree that you have completed?  
O Less than high school diploma or its equivalent (i.e. GED)  
O High school diploma or its equivalent  
O Some college, trade school, or university
33. Your name: __________________________________________________

You have reached the end of the questionnaire.
Please be sure to return your complete questionnaire to Cheryl Peters (778-888-3263)

Thank you very much for participating!
### Appendix B Task diaries used in the Outdoor Workers Project

<table>
<thead>
<tr>
<th>Date</th>
<th>Posture</th>
<th>Shade</th>
<th>Clothing/protection</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>05</td>
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</tbody>
</table>

### Name:

**Sampling day:** 1 2 3 4 5  
*(circle one)*

Did you wear sunscreen? YES NO

**OUTDOOR**

1
2
3
4
5
6
7
8
9
10
**INDOOR**

11 Indoor

### Name:

**Sampling day:** 1 2 3 4 5  
*(circle one)*

Did you wear sunscreen? YES NO

**OUTDOOR**

1
2
3
4
5
6
7
8
9
10
**INDOOR**

11 Indoor
Appendix C  Proposal to use the National Enhanced Cancer Surveillance System

NECSS data use proposal, Peters et al., University of British Columbia  April 24, 2013

Project title: Occupational exposure to solar ultraviolet radiation (UVR) and the risk of prostate cancer

Applicants and affiliations:

- Cheryl Peters, MSc, Co-Principal Investigator, PhD Candidate School of Population and Public Health, University of British Columbia
- Perry Hystad, MSc, Co-investigator, PhD Candidate School of Population and Public Health, University of British Columbia
- Mieke Koehoorn, PhD, Co-Principal Investigator, Associate Professor School of Population and Public Health, University of British Columbia. Note: Dr. Koehoorn will provide the academic oversight for this project.

Despite the fact that prostate cancer is the most common malignancy in Canadian men (aside from non-melanoma skin cancer), the etiology of the disease is not well-understood\(^1\).

One area of research that is receiving increasing attention is the link between solar ultraviolet radiation exposure and prostate cancer. It has been hypothesized that a decreased risk of prostate cancer among those men who have high exposure to solar ultraviolet radiation may be due to a protective effect offered by the vitamin D producing benefit of sun exposure\(^2\). There has also been recent evidence of an increased risk of prostate cancer with very high solar UV exposure in Australia, so the relationship remains poorly understood\(^3\).

We are interested in assessing the effect of occupational sun exposure on the risk of developing prostate cancer in Canada. We would like to conduct an analysis of prostate cancer cases and their controls in the NECSS. We will link the residential and work histories data together with a map of solar UV radiation intensity created from satellite data to estimate occupational sun exposure for each job held by the study participants. A job exposure matrix

\(^{3}\) Nair-Shalliker et al Int J Cancer. 2012 Sep 1;131(5):E726-32
for outdoor work has already been created by CAREX Canada\(^4\) and this linkage to spatial patterns of solar UV will allow us to effectively weight the outdoor jobs according to the predicted UV exposure levels from the satellite data. Various metrics of occupational sun exposure will be explored as predictors of prostate cancer outcomes (i.e. cumulative exposure, exposure at longest job held, the impact of age categories of outdoor exposure, etc.). To accomplish this work, we will require access to the mainfile (main survey - SES, diet, exercise, etc.), the occupational exposure file, and the residential history file.

Data items requested (for prostate cancer cases and controls)

**Personal information**
- Date of birth
- Ethnicity
- Education & income
- Smoking and tobacco behavior and history variables
- Height and weight
- Derived personal variables as related to variables listed

**Residential history**
- Address information
- Time period information
- Smokers living in the home

**Employment history**
- All job IDs and time periods
- Industry type
- Duties
- Location and job title
- Status (full-time, part-time, etc)
- Odours from industry
- Smoking on the job

**Work exposure to chemicals and other substances**
- Include all of the listed substances

**Diet information (include information from Ontario diet questionnaire as well)**

• Mineral/vitamin supplements
• Length of time taken vitamins
• Eating habits 2 years ago
• Food and drink variables (to create aggregate variables to control for vitamin D intake)
• Food intake 20 years ago
• Fish and game intake (Ontario)

Physical activity (include Ontario physical activity questions)
• All physical activity types, plus frequency and duration
• Derived physical activity variables

Other general information: Ontario questionnaire
• Smoking exposure in childhood
• Relatives with cancer
• Income variables
• Number of people in household