The burden of occupational cancer in Great Britain

Cutaneous malignant melanoma and occupational exposure to solar radiation

Report submitted to the IOSH Research Committee

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Executive summary

The aim of the overall project was to produce an updated estimate of the current burden of cancer for Great Britain resulting from occupational exposure to carcinogenic agents or exposure circumstances. The primary measure of the burden of cancer used in this project was the attributable fraction (AF) i.e. the proportion of cases that would not have occurred in the absence of exposure; this was then used to estimate the attributable numbers. This involved obtaining data on the risk of the disease due to the exposure of interest, taking into account confounding factors and overlapping exposures, and the proportion of the target population exposed over the period in which relevant exposure occurred. Estimation was carried out for carcinogenic agents or exposure circumstances classified by the International Agency for Research on Cancer (IARC) as definite (Group 1) or probable (Group 2A) human carcinogens. Here, we present estimates for **cutaneous malignant melanoma** that have been derived using incidence data for calendar year 2011, and mortality data for calendar year 2012.

Solar radiation has been classified by the IARC as a definite human carcinogen for cutaneous malignant melanoma. The risk for cutaneous malignant melanoma caused by occupational exposure to solar radiation is difficult to estimate because everyone at some time in their life is exposed to sunlight at a greater or lesser degree depending on residential location and leisure time activities. Some studies suggest that intermittent, relatively high exposure is likely to be important in occupational studies. Occupational exposure to solar radiation is usually measured via exposure categorisation (recreational or occupational) or job categorisation (indoor or outdoor). Outdoor work and farming has been associated with increased risk for cutaneous malignant melanoma, particularly in areas of relatively low sunlight, such as Britain.

Due to assumptions made about cancer latency and working age range, only cancers in ages 25+ in 2012/2011 could be attributable to occupation. For Great Britain in 2012, there were 1219 total deaths in men aged 25+ and 882 in women aged 25+ from cutaneous malignant melanoma. In 2011 there were 5800 total registrations for cutaneous malignant melanoma in men aged 25+ and 6159 in women aged 25+.

The estimated total (male and female) attributable fraction for cutaneous malignant melanoma is 2.01% (95%Confidence Interval (CI)=1.40%-2.72%), which equates to 48 (95%CI=33-64) deaths and 241 (95%CI=168-325) registrations attributable to occupational exposure to solar radiation. The estimated AF for men is 3.17% (95CI=2.18%-4.28) resulting in 39 (95%CI=27-52) and 184 (95%CI=127-248) attributable deaths and registrations respectively. For women the estimated AF is 0.92% (95%CI=0.71-1.32%) resulting in 8 (95%CI=6-12) attributable deaths and 57 (95%CI=41-77) attributable registrations. The main industries of concern are construction, agriculture, public administration and defence, and land transport.

1. Introduction

Doll and Peto (1981) estimated the proportion of cancer deaths in Britain due to occupational causes as 4% (with an uncertainty range from 2% to 8%), which equates to approximately 6,000 deaths per annum (with a range of 3,000 to 12,000). The aim of this project was to update the estimate of the burden of cancer in Britain due to occupation. This involved estimating the current overall attributable fractions (AF) and numbers of cancers due to occupation and the relative contribution of occupational carcinogens and carcinogenic processes. Evaluation was carried out for all carcinogenic agents and occupations classified by the International Agency for Research on Cancer (IARC) as a Group 1 (established) or 2A (probable) human carcinogens.

Results for over 20 cancer sites have been published previously in published papers including a dedicated supplement (Rushton *et al*, 2010; Rushton *et al* 2012) and full technical reports are available on the Health and Safety Executive (HSE) website (http://www.hse.gov.uk/cancer/).

This report extends the previous British study to estimate the burden of occupational cancer (Rushton 2012) and focuses on cutaneous malignant melanoma (CMM) (International Code of Diseases (ICD) version 10 code C43). The review does not cover ocular melanoma which has been associated with an increased risk in welders due to occupational exposure to artificial sources of ultraviolet radiation nor does it cover non-melanoma skin cancers (Young *et al* 2012; HSE 2012a,b).

2. Incidence and trends

This chapter briefly defines melanoma and its subtypes and describes trends in deaths and cancer registrations in Britain.

The cells that become cancerous in melanoma are called 'melanocytes' (Cancer Research UK 2014). They are mainly found between the dermis and epidermis, but are also found in many other places, including the hair and the lining of internal organs, such as the eye. The melanocytes produce a dark-coloured pigment called melanin, which is responsible for the colouring of the skin. The pigment helps to protect the body from the ultraviolet (UV) light of the sun, which can cause burns.

There are four main types of cutaneous melanoma: superficial spreading melanoma, nodular melanoma, lentigo maligna melanoma and acral lentiginous melanoma (Cancer Research UK 2008). Superficial spreading melanoma is the most common, accounting for about 70% of cases. This type of melanoma tends to grow outwards initially, then downward into the deeper layers of the skin. Approximately 25% of UK melanomas are nodular. These develop quickly and grow down into the skin, usually on infrequently exposed parts of the body. Lentigo maligna melanoma appears in areas of skin that get a lot of sun exposure and is largely restricted to the head and neck, especially the face. Acral lentiginous melanoma, by definition, is found on the skin of the palms of the hands and more commonly on the soles of the feet. Melanoma of the skin arises in different anatomic sites in men and women. The trunk (back, abdomen and chest) is the most common in men, accounting for 38%. Melanoma is most commonly found on the legs (including the hips and thighs) in women, accounting for 42%.

Sun exposure is the main cause of cutaneous melanoma, or more specifically solar UV radiation (Gruber and Armstrong 2006). Benign acquired nevi (those that develop after 6 months of age) and atypical nevi are also well-established risk factors for melanoma of the skin. Nevi are most likely to be associated with superficial spreading melanoma rather than other types. Congenital nevi (those present immediately at birth) are categorised by size, which corresponds to the malignant potential, thus cutaneous melanoma arising in small congenital nevi is rare.

Over 13000 newly diagnosed cases (cancer registrations) of CMM occur each year in the UK and approximately 2000 deaths. Numbers of deaths and newly diagnosed melanomas have increased steadily over the last decade (Tables 1 and 2). CMM survival rates have been improving over the past 25 years. Generally, the five-year relative survival rate varies between 20% and 90% depending on the stage of disease, thickness of the tumour and age at diagnosis (Cancer Research UK 2008).

Table 1 Number of malignant melanoma of the skin registrations in England, Wales and Scotland for 1995–2012

Year	Men			Women		
	England	Wales	Scotland	England	Wales	Scotland
1995	1833	104	245	2744	132	399
1996	1840	104	280	2647	125	414
1997	1998	113	278	2705	157	423
1998	2149	141	278	2851	182	355
1999	2161	137	289	2880	151	383
2000	2541	184	281	3280	211	378
2001	2638	185	315	3424	218	400
2002	2832	193	356	3584	270	499
2003	2971	199	343	3718	245	475
2004	3307	208	400	4056	250	497
2005	3663	215	401	4362	268	461
2006	4009	250	448	4649	266	547
2007	4148	285	461	4661	267	638
2008	4622	312	527	5073	303	660
2009	4707	310	538	5064	336	654
2010	5151	408	524	5505	330	621
2011	5,440	359	574	5681	382	630
2012		366	549		327	628

Source: ONS MB1 Series Table 1 (ONS 2014a), Welsh Cancer Intelligence & Surveillance Unit (WCISU 2014), Information Services Division (ISD 2014)

Table 2 Number of deaths from malignant melanoma of the skin in England, Wales and Scotland 1999–2012

Year	Men		Women	
	England and Wales	Scotland	England and Wales	Scotland
1999	762	71	714	60
2000	793	56	743	59
2001	758	79	712	66
2002	784	73	696	59
2003	837	78	748	68
2004	890	93	707	58
2005	855	87	767	71
2006	949	90	700	68
2007	988	94	837	70
2008	1008	93	839	78
2009	1044	101	814	84
2010	1115	114	832	81
2011	1167	105	832	71
2012	1110	115	810	75

Source: ONS DR Series Table 5.2 from 2006, DH2 Series Table 2.2 to 2005 (ONS 2014b), Information Services Division (ISD 2014)

3. Overview of aetiology

This chapter gives an overview of the main risk factors for CMM and findings from the Occupational Health Decennial Supplement for England regarding occupations with high levels of CMM.

The main risk factor for CMM is excess exposure to ultraviolet radiation, the principle source of which is the sun, particularly for Caucasians (Cancer Research UK 2008). Increased risk is most strongly linked to intermittent exposure to high-intensity sunlight (usually recreational and often resulting in sunburn), rather than chronic exposure, typical of outdoor occupations (Diepgen and Mahler 2002; Gruber and Armstrong 2006) although outdoor workers who have sustained repeated episodes of severe sunburn might be at increased risk (Gawkrodger 2004). Artificial UV radiation sources, such as sunbeds and sunlamps are also linked to an increased risk (Gallagher and Lee 2006) and sunbeds have recently been classified by the International Agency for Research on Cancer as carcinogenic to humans (Group 1) (El Gissassi *et al* 2009).

Individual susceptibility to solar radiation is influenced by skin pigmentation. A tendency to burn rather than tan consistently increases risk (Dubi 1986, Elwood *et al* 1986, Osterlind *et al* 1988, Gallagher *et al* 1986). Individuals with light hair, eye colour and skin are at increased risk (Elwood and Jopson 1997) as are those where freckles or acquired moles (melanocytic nevi) are present (Elwood *et al* 1984, Holman and Armstrong 1984).

The latest information relating occupation at the 2001 census and mortality is given in the Occupational Health Decennial Supplement for the period 1991-2000 in men and women aged 20–74 years in England (Table 3). For melanoma of the skin it was observed that the risk was greatest in compositors for men, and, architects and surveyors for women. In comparison to the previous supplement, sales managers, school teachers and aircraft flight deck officers are the only occupations that re-appear, with lower PMRs in male sales managers and school teachers and higher PMRs in male aircraft flight deck officers and female school teachers. In the recent Occupational Health Decennial Supplement various predominantly outdoor occupations do appear with significantly elevated PMRs, including professional athletes, sports officials, police officers and builders, building contractors (Coggon *et al* 2009).

Table 3 Job codes with significantly high PMRs for melanoma of the skin. Men and women aged 20–74 years, England 1991–2000

Job Group		**Deaths**	**Expected deaths**	**PMR**	**Lower 95% CI**	**Upper 95% CI**
SIC code	**Description**	**1991–2000**				
Men						
006	Sales Managers etc.	115	92.4	124.5	102.7	149.4
011	School Teachers	106	72.8	145.5	119.1	176.0
025	Professional athletes, sports officials	9	3.8	234.3	107.1	444.8
033	Architects and Surveyors	76	58.0	131.1	103.3	164.1
034	Aircraft Flight Deck Officers	12	4.9	245.4	126.8	428.7
041	General and office managers	105	80.6	130.3	106.6	157.8
049	Police	53	38.5	137.6	103.0	179.9
054	Postal Workers, Mail Sorters	51	35.1	145.4	108.2	191.2
094	Compositors	13	4.4	296.8	158.1	507.6
142	Other Electrical/Electronic Trades nes	59	36.9	159.7	121.6	206.0
143	Electrical Engineers (not professional)	38	23.5	161.6	114.4	221.8
169	Builders, Building Contractors	107	78.0	137.1	112.4	165.7
191	Dockers and Goods Porters	26	15.4	168.9	110.4	247.5
192	Refuse & Salvage Collectors	14	7.4	188.8	103.2	316.7
Women						
011	School Teachers	205	142.9	143.4	124	164.5
012	Vocational Trainers, Social Scientists etc.	33	21.1	156.4	108	219.7
033	Architects and Surveyors	6	2.1	291.2	107	633.9
060	Other Service Personnel	224	193.3	115.9	101	132.1

Source: Coggon *et* al. (2009) Occupational mortality in England and Wales, 1991-2000

IARC have assessed the carcinogenicity of a number of chemicals and those classified as causing melanoma (Group 1), or possibly causing melanoma (Group 2A), are given in Table 4. From the information included in the IARC assessments Siemiatycki *et al* (2004) further classified the evidence as strong or suggestive, which can also be found in Table 4. There is strong evidence that solar radiation and UV-emitting tanning devices such as sunbeds are associated with melanoma and suggestive evidence for ultraviolet radiation from artificial sources.

Table 4 Occupational agents, groups of agents, mixtures, and exposure circumstances classified by the IARC Monographs, Volume 100D (IARC, 2012), into Groups 1 and 2A, which have the cutaneous malignant melanoma as the target organ

Agents, Mixture, Circumstance	Main industry, Use	Evidence of carcinogenicity in humans*	Strength of evidence$	Other target organs
Group 1: Carcinogenic to humans				
Agents, groups of agents				
Solar radiation	Outdoor workers	Sufficient	Strong	Melanoma
Exposure circumstances				
UV-emitting tanning devices		Sufficient	Strong	Melanoma
Group 2A: Probably carcinogenic to humans				
Agents & groups of agents				
Ultraviolet radiation (A, B and C) from artificial sources	Arc welding; industrial photoprocesses; sterilisation and disinfection; phototherapy; operating theatres; laboratories; ultraviolet fluorescence in food industry; insect traps	Inadequate	Suggestive	Ocular melanoma in welders**
Exposure circumstances				
None identified				

* Evidence according to the IARC monograph evaluation
$ taken from Siemiatycki *et al* (2004)
** See Young *et al* (2012)

3.1 Cutaneous malignant melanoma and solar radiation

An overview of the ley literature on CMM resulting from exposure to solar radiation is given below.

Solar radiation is the combination of ultraviolet (UV) radiation and visible light that manages to reach the earth's surface (wavelengths greater than 280nm). UVB (280 to 315nm) is much more effective at producing cancer in animals, sunburn in humans, and DNA damage, than UVA (315 to 400nm) (De Fabo *et al* 2004). Exposure to the individual varies according to (i) environmental conditions such as the time of day, latitude, altitude and weather conditions and (ii) cultural and behavioural factors such as clothing preferences.

Reviews of occupational sun exposure

There have been a number of reviews assessing the association between exposure to solar radiation including during occupation, and CMM. Elwood and Jopson (1997), in a systematic review of published case-control studies of melanoma and sun exposure, classified exposure as relating to intermittent, occupational or total sun exposure and compared the highest reported exposure category to the lowest exposure category. Where possible, estimates were adjusted for demographic factors, such as age and sex, and susceptibility characteristics, such as ethnic origin and skin pigmentation. Overall, 29 studies contributed data on sun exposure yielding a significant positive risk (Odds Ratio (OR)=1.71, 95%CI=1.54-1.90, 6,934 cases, 23 studies) for intermittent exposure and a significantly reduced risk (OR=0.86, 95%CI=0.77-0.96, 6,517 cases, 20 studies) for heavy occupational exposure. However, results for the individual studies varied widely with eight showing increased risk and twelve showing a reduced risk. The authors surmise that the relationship between melanoma and occupational sun exposure may be non-linear with an increased risk related to small amounts of exposure, possibly due to intermittent outdoor work, and a decrease in risk for continued long heavy exposure, possibly due to constant solar radiation exposure resulting in an adequate protection mechanism.

Ramirez *et al.* (2005) conducted a review on occupational skin cancer and ultraviolet and other forms of radiation from available published papers. They found an increased risk of skin cancer (including melanoma) amongst outdoor workers. In particular, deaths from melanoma were increased for non-white farmers (Proportional Mortality Ratio (PMR)=2.3, OR=6, n=6), police officers (Standardised Incidence Ratio (SIR)=1.37, 90%CI=1.08-1.72), physical education teachers (SIR=2.01) and pilots and cabin attendants (SIR varies between studies from 1.8 to 10.20). The authors noted a lack of available information on other professionals who spend time outside as part of their job, such as professional cyclists.

A meta-analysis of 57 studies investigating sun exposure and cutaneous melanoma found a positive association for intermittent sun exposure, and, an inverse association with a high continuous pattern of sun exposure (Gandini *et al* 2005). Relative risks for sun exposure were extracted from fifty-seven studies published prior to September 2002, based on subjects aged over 20 years, of which forty-one were eligible for investigation of chronic (occupational) sun exposure. The majority of studies were carried out in European countries, with others being conducted in North America, Australia, New Zealand, Argentina, Brazil and Israel. There were several studies that presented risk estimates lower than one indicating an inverse association, the majority being non-significant. The pooled estimate showed a slight inverse association but was again non-significant (Relative Risk (RR)=0.95, 95%CI=0.87-1.04). On further investigation it was found that the variability between studies could be explained by "inclusion of controls with dermatological diseases" and "latitude". The pooled RR of the twenty-six studies that did not include dermatological diseased controls was 0.87 (95% CI=0.74-1.02), whereas the studies that did include them resulted in a significantly higher RR of 1.29 (95%CI=1.06-1.57). It was shown that living at higher latitudes gave a greater association between chronic sun exposure and melanoma. For the thirty-two studies that latitude was calculated, the pooled estimate was RR=0.98 (95%CI=0.85-1.12).

Farmers

In a meta-analysis by Acquavella *et al* (1998) a pooled estimate of 0.95 (95% CI=0.82-1.09) was found for white male farmers based on results from 21 studies. However, there was evidence of heterogeneity in the results for the different studies and the pooled estimates varied by the type of study design, RR=0.87 (95% CI=0.69-1.10), RR=0.94 (95% CI=0.84-1.04) and RR=1.14 (95%CI=0.74-1.47) for follow-up studies, PMR studies and case-control studies respectively.

Cerhan *et al* (1998) conducted a cancer mortality study on white male Iowa farmers aged over 20 years in 1987 to 1993. The final cohort consisted of 88,090 white male farmers, using a reference group of all deaths of Iowa decedents who were white male non-farmers. Overall farmers had an excess of deaths due to melanoma of the skin (PMR=1.17, 85%CI=0.94-1.45). However, the excess was only significantly elevated for younger farmers, aged 20-64 years (PMR=1.60, 95% CI=1.07-2.38). All estimates were adjusted for age. The authors state that this excess was consistent with occupational exposure to ultraviolet light.

A hospital based case-control study was conducted in five Italian rural areas to examine the association between cancer and farming among women (Settimi *et al* 1999). Altogether 1,044 newly diagnosed cancer cases, aged 20-75 years were ascertained from hospital records from March 1990 to September 1992, of which 26 were skin melanoma cases. The reference group was drawn from other cancer cases, excluding lung and non-melanoma skin cancer cases. All estimates were adjusted for age. Ever being employed as a farmer or farm labourer was associated with a statistically significant increased risk (OR=2.7, 95%CI=1.2-6.0, n=26), as did being engaged in agricultural jobs for 10-19 years (OR=6.6, 95%CI=2.2-19.0, n=5). Vine growing was non-significantly associated with an OR of 2.5 (95%CI= 0.4-14.8, n=8). Non-significant increases in risk were observed for length of employment of 1-9 years (OR=1.1, 95% CI=0.1-8.9) and over 20 years (OR=2.1, 95%CI=0.8-5.8). An excess risk was also found for growing vegetables (OR=1.4, 95%CI= 0.3-5.9, n=3). No associations were found for growing wheat or fruit-trees, 0.9 (95%CI= 0.2-5.4, n=7) and 0.7 (95%CI=0.1-5.2, n=1) respectively.

A case-control study in Ontario, Canada found that chronic exposure to solar UV radiation (indicated either by days of outdoor activity during adolescence (non-vacation and non-beach) or occupational outdoor hours in recent adult life) was associated with a significantly reduced risk of malignant melanoma (Walter *et al* 1999). For recent occupational exposure the adjusted OR was 0.78 (95% CI= 0.61-0.99) with similar results for location of the tumour, 0.82 (95% CI=0.60-1.12) and 0.74 (95% CI=0.56-0.99) for trunk and non-trunk respectively.

Lee *et al.* (2002) conducted a proportionate mortality analysis on 267,479 farmers from 26 states in the US who worked in the crop (n=222,549) or livestock (n=44,930) industry. Death certificate information was collected from the National Occupational Mortality Surveillance database for the years 1984-1993. The reference group was all deaths among decedents in the database. All estimates were age adjusted. For melanoma of the skin estimates were produced for white male farmers only which gave PMR=95 (95%CI= 87-105, n=459) and PMR=110 (95%CI=92-132) for crop and livestock farmers respectively. Investigating age revealed a significant increase in young (aged 15-64 years) livestock farmers with PMR=150 (95%CI=110-200, n=47). Young crop farmers also had an excess risk but this was non-significant (PMR=106, 95% CI=88-125, n=131). Older (over 65 years) farmers in both groups had non-significant decreased risks of 92 (95%CI=82-103, n=328) for crop farmers and 95 (95% CI=75-119, n=76) for livestock farmers. No combined estimates were given for all white male farmers or for all farmers (white male, non-white male, white female and non-white female).

Koutos *et al* (2010) reanalysed cancer incidence in the US Agricultural Health Study (AHS), a large prospective study of private and commercial licensed pesticide applicators and spouses of private applicators. A deficit of CMM was found for private applicators (SIR=0.89, 95%CI 0.76, 1.03) and slightly raised risk for public applicators (SIR=1.09, 95%CI 0.58, 1.86) and for spouses (SIR= 1.17 95%CI 0.94, 1.43). Relative to the overall deficit of cancers in the AHS study, among spouses a significant relative excess of melanoma RSIR= 1.64 (95% CI 1.33, 2.02) was found.

Outdoor working

Vågerö *et al* (1986) conducted an analysis based on cases diagnosed as malignant melanoma in Sweden between 1961 and 1979. The cancer cases were obtained from the extended Swedish Cancer Environment Registry and included all men and women who were born in the period 1896-1940 and were economically active at the Population Census of 1960. The population under study consisted of 2,630,458 individuals who were classified into three exposure groups: office workers, other indoor workers and outdoor workers, based on their occupation code and description. There were 4,706 cases of malignant melanoma. The entire working population was used for reference. Overall the morbidity ratios, standardised for age and county of residence (in 1960), showed a negative association between melanoma and outdoor workers (Standardised Mortality Ratio (SMR)=86, 95% CI=81-92) and indoor non-office workers (SMR=94, 95% CI=90-98). A significantly elevated risk was discovered for office workers (SMR=131, 95% CI=124-138). This trend remained present when the analysis considered only melanomas on covered parts of the body (trunk, upper limb and lower limb). However, when melanomas on uncovered parts of the body (eyelids, ear/auricular canal, face and scalp/neck) were investigated there was an elevated risk for all outdoor workers (SMR=107, 95% CI=92-123). After adjusting for social class the risk of melanoma on uncovered parts of the body remained elevated (SMR=109, 95% CI=94-126), and the risk for covered parts slightly increased (SMR=90, 95%CI=83-97). The authors note that there is a possibility that within each social class the patterns of sunlight exposure are different for the three groups and this cannot be entirely ruled out.

Garland *et al* (1990) conducted a study investigating the association between occupational sunlight exposure and melanoma in the US Navy. A total of 176 cases of cutaneous melanoma were identified in active-duty white males enlisted as Navy personnel in the period 1974 to 1984. Based on a review of job descriptions, individuals were categorised as indoor, outdoor or indoor and outdoor workers. The US civilian population was used for reference. The SEER (Surveillance Epidemiology and End Results) average annual age-adjusted incident rate was 9.2 per 100,000. Outdoor workers had a slightly higher rate of 9.4 per 100,000 (indoor workers were higher at 10.6 per 100,000). For all workers combined, melanoma occurred most frequently on the trunk, this rate was significantly elevated for outdoor workers (3.9 per 100,000, p-value<0.05). In particular, two occupations yielded statistically significant increases in risk for melanoma. These were aircrew survival equipment men (SIR=6.8, 95% CI=2.5-14.7) and enginemen (SIR=2.8, 95% CI=1.3-5.1). However, these two occupations are carried out primarily indoors. Potential confounding genetic factors and recreational sun exposure were not taken into account in this study. The authors note that: "if persons genetically at higher risk of melanoma migrate into indoor occupations, then for this reason alone indoor occupations may appear to be at higher risk of melanoma than outdoor occupations".

A case-control analysis was conducted using data recorded by the Los Angeles County Cancer Surveillance program (Goodman *et al* 1995). Records were collected for all cancer cases among adult white males without Spanish surnames who were aged between 20 and 65 years in the period 1972 to 1990. In total there were 3,527 cutaneous melanoma cases and 53,129 other cancer cases used for reference. Among other aspects, exposure to sunlight during work was examined. Job titles were blindly categorised into three categories: mainly indoor (reference category), indoor/outdoor or mainly outdoor. For the two non-reference exposure categories, the age adjusted proportionate incidence odds ratios were close to that expected (OR=0.97 for indoor/outdoor and OR=0.78 for mainly outdoor). However, when the estimates were further adjusted to take into account birthplace (as a substitute for sun exposure in childhood and adolescence) and education, there were elevated risks for melanoma, 1.16 (95%CI=1.07-1.27) and 1.15 (95%CI=0.94-1.40) for indoor/outdoor and mainly outdoor respectively. On investigating anatomical location of the cases, there were slightly elevated ORs for face/head/neck and trunk for outdoor workers (OR=1.26, 95% CI=0.78-2.05 and OR=1.28, 95% CI=0.99-1.67). In terms of occupations for the non-reference groups, many had significantly elevated OR estimates, some of which include sign painter/letterer, surveyor and chemical engineer. The authors suggest that lifestyle factors associated with higher education levels may be more important than work environment on melanoma risk.

Miller and Beaumont (1995) conducted a proportionate mortality study of various causes of deaths among California veterinarians from January 1960 through December 1992. Deceased veterinarians were identified from archived files from the California State Board of Examiners in Veterinary Medicine and a computerised list from the American Veterinary Medical Association. The study consisted of 450 veterinarians (430 white males, 6 non-white males and 14 white females). Mortality from malignant melanoma was significantly higher than expected (SPMR=3.25, 95%CI=1.62-6.52, n=7). The one observed death of cancer of the eye was also melanoma, which yielded a significant estimate (SPMR=12.41, 95%CI=2.70-56.96). All the deaths due to malignant melanoma were in white males. Analyses by race and sex gave similar estimates (white males: SPMR=3.47, 95%CI=1.74-6.94; white total: SPMR=2.23, 95% CI=1.61-6.49 and males total: SPMR=3.46, 95%CI=1.73-6.92). Self-employed and employee veterinarians had significantly elevated mortality from malignant melanoma: SPMR=2.68 (95%CI=1.05-6.85, n=4) and SPMR=6.05 (95%CI=1.81-20.27, n=2) respectively. Deaths from malignant melanoma were significantly elevated in individuals who had been employed in the profession between 20-29 years (SPMR=4.48, 95%CI=1.27-15.78, n=2) and 30 or more years (SPMR=3.86, 95%CI=1.35-11.00, n=3).

All deaths from melanoma between 1984 and 1991 in 24 states in the US were analysed by Freedman *et al* (1997). Cases were from a 24 state mortality database, aged 20 and over and identified as either white or African American. Two controls were selected from non-cancer deaths in the database and matched by sex, race and age. Potential sunlight exposure was assessed by state of residence and usual occupation recorded on the death certificate. Mean residential sunlight exposure was collected from the United States Weather Bureau and each state was characterised as low sun, moderate sun or high sun exposure. Occupations were classified by an industrial hygienist into four categories: indoor work, combined indoor and outdoor work, outdoor work by non-farmers and farming. For non-farming occupational sunlight exposure, the risk of melanoma was close to that expected (OR=0.99, 95%CI=0.87-1.12), whereas farmers were at significantly increased risk compared to indoor workers (OR=1.31, 95%CI=1.14-1.52). The risk of melanoma was found to be elevated among outdoor workers with low and moderate residential sunlight exposure (OR=1.22, 95%CI=0.99-1.50 and OR=1.05, 95%CI=0.86-1.29 respectively). The estimates were adjusted for age, sex, race, residential sunlight exposure and socioeconomic status. There was no clear pattern of risk associated with occupational exposure across sex, race or age groups.

A case-control study in Ontario, Canada found that chronic exposure to solar UV radiation was associated with a significantly reduced risk of malignant melanoma (Walter *et al* 1999). Eligible cases were individuals who had been newly diagnosed with cutaneous melanoma, were 20-69 years of age at diagnosis, lived in one of six counties in southern Ontario and were diagnosed through one of the hospitals or a private pathology laboratory between 1984 and 1986. Controls were randomly selected from property tax assessment rolls and were matched to cases based on age, sex and residence. Non-whites and non-English speaking individuals were excluded from the study. Chronic exposure was indicated either by days of outdoor activity during adolescence (non-vacation and non-beach) or occupational outdoor hours in recent adult life. For recent occupational exposure the adjusted odds ratio was 0.78 (95%CI= 0.61-0.99). Investigating body location of the tumour gave similar results, 0.82 (95%CI=0.60-1.12) and 0.74 (95%CI=0.56-0.99) for trunk and non-trunk respectively. For the four tumour subtypes (superficial spreading/on situ, nodular, lentigo maligna and other/unclassifiable) the estimates varied from 0.49 to 0.86. The estimates were adjusted for age, sex and initial reaction to summer sun (burning or not burning). The authors conclude that their results provide qualified support that intermittent UV exposure may carry an elevation in melanoma risk and, conversely, that chronic exposure may provide some protection.

Travier *et al* (2003) used the nationwide, Swedish Cancer Environment Registry III to compare cancer incidence among male veterinarians to that of the remaining active population (excluding other occupational groups that have extensive contact with animals, such as breeders, hunters and butchers). Individuals were followed for cancer incidence and mortality from January 1971 to December 1989, focusing on males who were employed as veterinarians or in veterinary medicine in either the 1960 or the 1970 census. A total of 1,178 male veterinarians were identified. Within the group individuals were categorised into one of three sub groups: veterinarians in the veterinary industry, veterinarians in other industries, workers other than veterinarians in the veterinary industry. However, when these three subgroups were analysed separately, any workers employed as a veterinarian in one census and as a non-veterinarian in the veterinarian industry in the other were excluded. For males identified as veterinarians or other workers of the veterinary industry a significant increase in risk was observed for melanoma of the skin (SIR=2.86, 95%CI=1.43-5.13, n=11) compared to the remaining active male population. For the subgroups an increased risk was observed in all three, veterinarians in the veterinary industry RR=2.77 (95% CI=1.24-6.17, n=6) which mainly arose on the trunk (RR=4.80, 95%CI=1.99-11.55, n=5), veterinarians in other industries RR=1.84 (95%CI=0.26-13.08, n=1) and other workers in the veterinary industry RR=3.12 (95%CI=1.01-9.67, n=3). A significant increase was also found just for veterinarians employed at the 1960 or 1970 censuses (RR=2.33, 95%CI=1.16-4.67, n=8) when compared to the rest of the male employed population with the highest income and education. RRs were adjusted for age, calendar period, geographic region and urban setting. The authors conclude that the excesses observed for melanoma could not be explained by the high socio-economic status of veterinarians, as the excess remained when comparisons were made with other high socio-economic groups. They also note that the results may reflect the carcinogenicity of occupational exposures including solar radiation.

Cancer incidence among indoor and outdoor working longshoremen in Genoa was retrospectively studied (Puntoni *et al* 2005). In total 4,993 longshoremen that were ever employed at the dock of Genoa between 1933 and 1980 were included in the study. They were employed at one of two dockyard trading companies: the "Stefano Canzio" and "San Giorgio". Cancer incidence was obtained from the Genova Cancer Registry for 1986–1996. According to their prevalent pattern of occupational sunlight exposure, eligible individuals were categorised as an indoor (n=2,451) or outdoor (n=2,101) worker. The male population of the City of Genova was used for reference and estimates were adjusted for age. A statistically significant excess risk of cutaneous melanoma was observed for outdoor workers (SIR=288, 95%CI=125-568, n=8). No excess was observed among indoor workers (SIR=97, 95% CI=20-284). When outdoor workers were compared to indoor workers, a higher incidence for melanoma was observed (RR=2.97, 95%CI=0.71-17.41) although this was non-significant. The authors note that the non-significance is due to similar exposures being shared by the two subgroups, and the lower statistical power obtained by using an internal rather than external reference group. The threefold increased risk detected only among outdoor workers supports the causal role of exposure to sunlight.

Site of the melanoma

More recently interest has centred on evaluating the nature of sun exposure and occurrence of CMM on different parts of the body and there has been discussion about whether melanomas at different anatomic sites may be due to different causal pathways. Chang *et al* (2009) in a pooled analysis of 15 case-control studies found that high sunbathing and total recreational sun exposure increased risk of melanoma of the trunk and limbs but not melanoma of the head and neck. Occupational sun exposure appeared neither to increase nor decrease risk of melanoma on the trunk and limbs but tended to risk of melanoma on the head and neck especially at low latitudes (OR=1.7 95% CI 1.0–3.0) (adjusted for effects of age, sex, hair colour, ability to tan and freckling. Only three of the 15 studies included by Elwood and Jopson were included in this paper with many being much more recent.

The same pattern was found in a case-control study not included in the paper by Chang *et al.* (Whiteman *et al* 2006) in which cutaneous melanomas developing on the head and neck were significantly more likely to occur in people with high levels of total sun exposure during adulthood, whereas melanomas on the trunk tended to occur on people with lower levels of sunlight exposure overall, but who reported higher levels of recreational exposure on the chest and back. They found that outdoor workers had a relative excess of head and neck melanomas and a deficit of melanomas at other body sites, similar to other studies. The authors suggest that this might appear to be associated with chronic exposure to high levels of sunlight which is in contrast to the many studies suggesting the role of intermittent exposure. One reason put forward by the authors for this apparent contradiction is that the site at which a melanoma develops reflects the susceptibility of host melanocytes to proliferate in response to sunlight i.e. people with an inherently low propensity to develop nevi require high levels of sunlight to develop melanoma and their tumours will tend to arise on habitually exposed sites such as the head and neck.

General limitations of the studies

Several different types of epidemiological study designs have been used in the literature reviewed, including cohort, case-control (population, hospital and registry-based) and cross-sectional studies. All have their advantages and disadvantages and these need to be taken into account when weighing up the strength of all the evidence. Cohort studies require a long follow-up to achieve sufficient numbers of cases for analysis and may suffer from loss to follow-up and changes in occupational and other circumstances. Case-control studies are by nature retrospective and thus may suffer from recall bias. Cross-sectional studies only provide information at one point in time making inference of causal relationships between exposure and disease outcome difficult to assess.

Many of the studies reviewed were case-control studies based on cases identified from hospital or population registers thus increasing the likelihood of accurate diagnosis of melanoma. More problematical is the retrospective nature of the exposure assessment with most studies being based on interview (face-to-face, by post or telephone) and recall of sun exposure both during leisure and occupational activities. Recall bias may have increased in more recent studies as awareness of the hazards of sun exposure became more common.

Exposure assessment of sun exposure is complex being a combination of frequency, intensity and duration. However, there appear to be no accepted definitions for capturing these components or for the levels and categories that are of importance to the development of melanoma. The studies therefore varied considerably in the amount and detail of information collected on sun exposure. Several estimated 'life time' or total numbers of hours of occupational and recreational exposure in winter and summer (e.g. Mackie and Aitchison 1982, Green *et al* 1986). Often a large amount of potentially relevant information was collected such as number of weeks on vacation in a sunny area, the usual number of hours spent outdoors during occupation and recreation in different seasons, detail of activities such as sunbathing and clothing normally worn. This sometimes led to a multiplicity of variables being derived for analysis or some form of complex index or scoring system.

In addition the adjustment of risk estimates of the association between occupational sun exposure and melanoma for other risk factors and confounders varied between studies, partly depending on the information collected. Adjustment for hair and/or skin colour, ethnicity and freckling was fairly common. Other adjustment variables sometimes included were tendency to burn, educational level or socio-economic status, use of sun screen and recreational sun exposure.

A further challenge in the design of epidemiological studies is the choice of a comparison population. In the case-control studies reviewed many used hospital patients as controls. Some of these were patients with other dermatological conditions or malignancies other than melanoma (Graham *et al* 1985) who may have been more aware about the effects of sun exposure.

4. Attributable Fraction estimation

Chapter 4 gives details of the data used for estimation of the burden of CMM from occupational exposure to solar radiation and the results overall, for males and females separately and by industry sector.

4.1 General considerations

Data relevant to the calculation of AF

The two data elements required are an estimate of relative risk (RR), and either (1) an estimate of the proportion of the population exposed (p(E)) from independent data for Great Britain, or (2) an estimate of the proportion of cases exposed (p(E|D)) from population based study data.

The RR chosen from a 'best study' source is described for each exposure, with justification of its suitability. Information on the 'best study' and independent data sources for the proportion of the population exposed are also summarised for each exposure in the appropriate section below. In the absence of more precise knowledge of cancer latency, for solid tumours a latency of up to 50 years and at least 10 years has been assumed for all types of the cancer. Therefore it is assumed that exposure at any time between 1963 and 2002 (the Risk Exposure Period, REP) can result in a cancer being recorded in 2011 as a registration or in 2012 as an underlying cause of death. Although strictly speaking the REP for cancer registrations recorded in 2011, the year for which estimation has been carried out, would be 1962-2001, for simplification the years 1963 to 2002 have also been used, as for deaths, as the proportion exposed will not be affected. For an independent estimate of the proportion of the population exposed, numbers of workers ever exposed during this period are estimated by extrapolating from a point estimate of exposed workers taken from the period. For solar radiation this is from the CARcinogen EXposure Database CAREX (Pannett *et al* 1998) relating to 1990-93. Data are not available on the levels of exposure in all industry sectors for the carcinogens included in CAREX, nor the numbers exposed at these levels. The industry sectors were thus allocated to 'higher' or 'lower' exposure categories assuming distributions of exposure and risk that corresponded broadly to those of the studies from which the risk estimates were selected. The initial allocations were based on the judgment of an experienced human exposure scientist. Each assessment was then independently peer-reviewed and if necessary, a consensus assessment agreed. An adjustment is made to take account of gross changes in employment levels which have occurred particularly in manufacturing industry and the service sector across the REP. A turnover factor is applied to estimate numbers ever exposed during the REP, determined mainly by the estimate of staff turnover per year during the period. The point estimate of numbers employed are in Table 5 below, and the adjustment factors for CAREX and the staff turnover estimates are in Table A1 in the Statistical Appendix. The assumptions made about the age of entry into the workforce from staff turnover was that this occurred between the ages of 15 and 44, and retirement was at age 65 for men and women. The resulting estimate of numbers ever exposed during the REP is given in Table 6. Other estimates used in the calculations that remain constant across exposures (unless otherwise stated) are given below:

- Number of years in REP = 40
- Proportion in the workplace ever exposed is set to one, i.e. all are assumed to be exposed, in the absence of more detailed information.

- Numbers ever of working age during the target REP = 20.8 million men, 22.2 million women (2012 population estimates). This is the denominator for the proportion of the population exposed, and is based on population estimates by age cohort in the target year.

- Total deaths from malignant melanoma of the skin in GB in 2012 = 1,219 for men aged 25+ (1,104 England and Wales and 115 Scotland), 882 for women aged 25+ (807 England and Wales and 75 Scotland).

- Total registrations for malignant melanoma of the skin in GB, averaged over 2008 to 2011 for England and 2008 to 2012 for Wales and Scotland = 5,800 for men aged 25+ (4,917 England, 347 Wales and 536 Scotland), 6,159 for women aged 25+ (5,212 England, 327 Wales and 620 Scotland).

Attributable numbers are estimated by multiplying the AF by the total number of cancers in GB. Only cancers which could have been initiated during the risk exposure period are counted, taking normal retirement age into account. Therefore for solid tumour cancers, total deaths or registrations recorded at all adult ages (25+) are used to estimate attributable numbers. An age specific estimator has been used for malignant melanoma due to occupational exposure to solar radiation, so that Attributable Fractions are estimated separately for each five-year age group and applied to total deaths or registrations in that age group.

For each agent where data on worker numbers are only available for men and women combined (CAREX data), the assumed percentage of men is given in addition to the numbers exposed. The allocation to high and low, and occasionally negligible, exposure level categories, or division into separate exposure scenarios, is also included in these tables.

Full details of the derivation of the above factors and the methods of calculating AF are published separately (Hutchings and Rushton; HSE 2011). Unless otherwise stated, Levin's method is used for estimates using independent estimates of numbers exposed, as used here for solar radiation, and Miettinen's method is used for study-based estimates. A summary of the methodology is given in the Statistical Appendix. For this analysis an age-group specific estimator for the Attributable Fraction has been used, with results given also using the non-age-specific estimator in the appendix so that comparisons can be made with the other results from the main British burden study, which used this methodology.

4.2 Solar radiation

(a) Risk estimate:

The risk for malignant melanoma caused by occupational exposure to solar radiation is difficult to estimate because everyone at some time in their life is exposed to sunlight at a greater or lesser degree depending on residential location and leisure time activities. Some but not all epidemiological studies have attempted to adjust risk estimates for non-occupational solar exposure. Typically, residential location is used as a surrogate for recreational sunlight exposure. There is uncertainty regarding the nature of how malignant melanoma develops regarding type of solar exposure although some studies suggest that intermittent, relatively high exposure is likely to be important in occupational studies.

Occupational exposure to solar radiation is usually measured via exposure categorisation (recreational or occupational) or job categorisation (indoor or outdoor). Outdoor work has been associated with an elevated risk of malignant melanoma (Goodman *et al* 1995; Puntoni *et al.* 2005; Garland *et al.* 1990). A consistently elevated risk has been observed for farmers (Cerhan *et al* 1998; Settimi *et al* 1999; Freedman *et al* 1997) and veterinarians (Miller and Beaumont 1995; Travier *et al* 2003).

Goodman (1995) in a case-control analysis of cancer registry data in Los Angeles County, found proportional ORs, adjusted for age, educational level and birthplace, of 1.16 (95%CI=1.07-1.27) for mixed indoor/outdoor occupations and 1.15 (95%CI=0.94-1.40) for outdoor occupations relative to indoor occupations.

Freedman (1997), in a large US case-control study, estimated the risk associated with occupational sun exposure, adjusted for age, sex, race, socioeconomic status and farming occupation, was 0.92 (95%CI=0.87-0.98) for mixed indoor and outdoor occupations, 0.99 (95%CI=0.87-1.12) for outdoor non-farmer exposure, and 1.31 (95%CI=1.14-1.52) for farmers relative to indoor work. Additional adjustment for residential exposure in areas of low sunlight gave an OR=1.22 (95%CI=0.99-1.50) for non-farming outdoor exposure.

For the estimation of burden of melanoma due to occupational solar radiation exposure we have used risk estimates from the study by Freedman (1997) as this provides estimates adjusted for appropriate confounders and also for different levels of sunlight exposure. Britain has relatively low sunlight exposure generally. The risk estimate, adjusted for residential exposure in areas of low sunlight for non-farming outdoor exposure (1.22, 95%CI=0.99-1.50) has been therefore been used for 'higher' exposures (O) and the risk estimate 1.31 (95%CI=1.14-1.52) has been used for farmers (F) (Table 6). As the risk estimate for mixed indoor/outdoor exposure (M) from Freedman is less than 1 this has been set to 1.

(b) Numbers exposed:

CAREX estimated about 1,250,000 workers were exposed to solar radiation in Great Britain between 1990 and 1993. The numbers of workers exposed to solar radiation in the various industries covered are given in Table 5. The CAREX exposed workers are assumed to be either 'outdoor' workers (O) and therefore highly exposed, subject to 'mixed' exposure or 'lower' exposed (M) or having exposure at 'farmers' level (F). The percentage of males is taken as that for all occupations from the 1990 census within the group industry sectors.

Table 5 Numbers of workers exposed to solar radiation according to CAREX in 1990-1993

Code	Industry	CAREX Data 1990-1993		
		Number Exposed	Number in Industry	Exposure Level
11	Agriculture and hunting	159533	419825	F
12	Forestry and logging	9860	14500	F
13	Fishing	8079	16150	O
23	Metal ore mining	405	1225	O
29	Other mining	11260	28150	O
311-2	Food manufacturing	8288	414150	M
322	Manufacture of wearing apparel, except footwear	5685	189500	M
331	Manufacture of wood and wood and cork products, except furniture	17287	132975	M
342	Printing, publishing and allied industries	31922	354750	M
353	Petroleum refineries	2528	18075	O
361	Manufacture of pottery, china and earthenware	8144	54450	O
362	Manufacture of glass and glass products	6484	43275	M
369	Manufacture of other non-metallic mineral products	10633	70875	M
371	Iron and steel basic industries	1937	48425	M
372	Non-ferrous metal basic industries	3173	79325	O
381	Manufacture of fabricated metal products, except machinery & equipment	8769	292200	M
384	Manufacture of transport equipment	54828	456900	M
41	Electricity, gas and steam	18330	140975	O
42	Water works and supply	9035	45175	O
5	Construction	350701	1753450	O
6	Wholesale and retail trade and restaurants and hotels	75349	4459525	M
711	Land transport	84287	671050	M
712	Water transport	8864	68175	M
719	Services allied to transport	37950	180725	M
72	Communication	66984	459425	M
8	Financing, insurance, real estate and business services	50081	2830800	M
91	Public Administration and Defence	117245	1557875	O
92	Sanitary and similar services	32910	274225	O
932	Research and scientific institutes	7288	91100	M
933	Medical, dental, other health and veterinary services	8864	1435675	M
934	Welfare institutions	3724	741375	M
935-9	Business, professional and other organisation	14231	133075	M
94	Recreational and cultural services	26732	534600	O
95	Personal and household services	6592	686750	O
	TOTAL	**1267982**	**18698725**	
	Main Industry Sector		% Male	
A-B	Agriculture, hunting and forestry; fishing	177472	79%	
C-E	Mining/quarrying, electricity/gas/steam, manufacturing industry	198708	71%	
F	Construction	350701	91%	
G-Q	Service industries Armed forces	423856 117245	46% 93%	

(c) AF calculation

The estimated total (male and female) attributable fraction for CMM is 2.01% (95%CI=1.40%-2.72%), which equates to 48 (95%CI=33-64) deaths in (2012) and 241 (95%CI=168-325) registrations (in 2011) attributable to occupational exposure to solar radiation. The estimated AF for men is 3.17% (95CI=2.18%-4.28) resulting in 39 (95%CI=27-52) and 184 (95%CI=127-248) attributable deaths and registrations respectively. For women the estimated AF is 0.92% (95%CI=0.71-1.32%) resulting in 8 (95%CI=6-12) attributable deaths and 57 (95%CI=41-77) attributable registrations (Table 6). Table 7 gives numbers of registrations attributable to occupational exposure to solar radiation by five-year age groups.

These estimates have been obtained using an age-adjusted approach with the assumption that workers enter the workforce between the ages of 15 and 45 only, and retire at age 65. Results are also given in Table 6a in Section 6 for an alternative estimation method using an unadjusted age approach which was in the previous burden of occupational cancer estimates for which entry ages of between 15 and 24 were assumed.

Table 6 Results for cutaneous malignant melanoma and exposure to occupational solar radiation

	Men			Women			Total		
	Number	**LL**	**UL**	**Number**	**LL**	**UL**	**Number**	**LL**	**UL**
Numbers ever exposed	3,112,940			1,709,973			4,822,913		
Proportion of the population exposed	14.97%			7.70%			11.22%		
Malignant Melanoma									
Attributable Fraction	3.17%	2.18%	4.28%	0.92%	0.71%	1.32%	2.01%	1.40%	2.72%
Attributable deaths (2012)	39	27	52	8	6	12	48	33	64
Attributable registrations (2011)	184	127	248	57	41	77	241	168	325
Years of Life Lost	660	441	863	160	116	216	820	557	1,079
Disability-adjusted Life-years	826	546	1,100	212	154	295	1,038	700	1,394

Abbreviations: LL=lower limit of 95% confidence limit; UL=upper limit of 95% confidence limit

Table 7 Numbers of attributable registrations (2011) for cutaneous malignant melanoma and exposure to occupational solar radiation by age group[1]

	Men			Women			Total		
Age group	**Number**	**LL**	**UL**	**Number**	**LL**	**UL**	**Number**	**LL**	**UL**
15-19	0	0	0	0	0	0	0	0	0
20-24	0	0	0	0	0	0	0	0	0
25-29	0	0	0	0	0	0	0	0	0
30-34	0	0	0	0	0	0	0	0	0
35-39	1	0	3	1	0	1	2	0	4
40-44	3	1	7	2	0	3	5	1	10
45-49	8	1	15	3	1	7	11	2	21
50-54	14	3	28	5	1	11	19	4	38
55-59	22	4	42	7	2	13	29	6	55
60-64	35	7	67	11	2	21	46	9	87
65-69	34	7	63	9	3	18	43	9	80
70-74	34	6	65	9	2	17	43	8	83
75-79	20	5	37	6	1	11	26	6	48
80-84	8	2	16	3	1	5	11	2	22
85+	3	1	7	1	0	3	5	1	9
Total	**184**	**127**	**248**	**57**	**41**	**77**	**241**	**168**	**325**

Abbreviations: LL=lower limit of 95% confidence limit; UL=upper limit of 95% confidence limit

(1) Cancer registration estimates in this table are for these age groups in 2011 (the target year). The age breakdown is based on assumptions that the age of entry into the workforce through staff turnover is from 15 to 44 years and retirement is at age 65. Data are not available for the actual age breakdown of the workforce ever exposed over the risk exposure period (1963-2002).

4.3 Industry results

Table 8 shows for industry categories from CAREX attributable registrations in 2011 and Table 9 shows attributable deaths in 2012. Only industries with at least 1 attributable registration are shown. The main industries of concern are construction, agriculture, public administration and defence, and land transport.

Table 8 Attributable cancer registrations for malignant melanoma by industry

Industry/Job category	Exposure level category*	Main Industry Sector	Registrations	Registrations	Registrations
			MEN	WOMEN	TOTAL
Agriculture and hunting	F	A-B	40	15	55
Construction	O	F	90	11	101
Electricity, gas and steam	O	C-E	4	2	6
Fishing	O	A-B	1	1	2
Forestry and logging	F	A-B	2	1	3
Land transport	O	G-Q	8	13	21
Other mining	O	C-E	3	0	3
Personal and household services	O	G-Q	1	1	2
Petroleum refineries	O	C-E	1	0	1
Public administration and defence	O	G-Q	23	2	26
Recreational and cultural services	O	G-Q	3	4	7
Sanitary and similar services	O	G-Q	3	5	8
Water transport	O	G-Q	1	1	2
Water works and supply	O	C-E	2	1	3
Total	**Total**	**Total**	**184**	**57**	**241**

*F=Farmer, O=Outdoor worker

Table 9 Attributable cancer deaths for malignant melanoma by industry

Industry/Job category	Exposure level category	Main Industry Sector	Deaths	Deaths	Deaths
			MEN	WOMEN	TOTAL
Agriculture and hunting	F	A-B	9	2	11
Construction	O	F	19	2	21
Electricity, gas and steam	O	C-E	1	0	1
Fishing	O	A-B	0	0	0
Forestry and logging	F	A-B	1	0	1
Land transport	O	G-Q	2	2	4
Other mining	O	C-E	1	0	1
Personal and household services	O	G-Q	0	0	0
Petroleum refineries	O	C-E	0	0	0
Public administration and defence	O	G-Q	5	0	5
Recreational and cultural services	O	G-Q	1	1	1
Sanitary and similar services	O	G-Q	1	1	1
Water transport	O	G-Q	0	0	0
Water works and supply	O	C-E	0	0	1
Total	**Total**	**Total**	**39**	**8**	**48**

*F=Farmer, O=Outdoor worker

5. Discussion

We estimate that 2% of all CMM occurring in Britain can be attributed to occupational exposure to solar radiation giving 48 attributable deaths and 241 newly occurring cancers. The industry of most concern is the construction industry (44% of the deaths and 42% of the registrations), followed by agriculture, public administration and defence, and land transport. These results confirm the concern about occupational solar radiation exposure arising from our previous estimate for non-melanoma skin cancer (NMSC) (AF=2.4%, 12 attributable deaths and 1,541 attributable registrations (Young *et al* 2012). Construction and public administration and defence were also highlighted for NMSC. Due to the known under-reporting of NMSC in Britain these figures are likely to be an underestimate the true burden. It is not thought that malignant melanoma is underreported as this is most likely to require hospital treatment.

As pointed out in section 3, assessment of the literature relating to occupational solar radiation is often hampered by inadequate definition of the type of skin cancer studied, the use of different methods for assessing exposure and variable adjustment for non-occupational exposure and other risk factors. Risk estimates thus vary substantially between studies, particularly for melanoma.

The assumptions made in the methodology used for this study may have introduced uncertainty or bias in the estimates, For CMM there was no good quality British study of workplace exposure to solar radiation and the study chosen may not have completely reflected exposures experienced in Britain. There was a general paucity of available information on separate risk estimates for men and women and for many carcinogens, including solar radiation, the risk estimates for men were used for women. In addition most estimates were for mortality rather than incidence. Epidemiological studies of occupational groups are often confounded by a 'healthy worker effect' i.e. a reduced overall risk estimate compared to the general population. This together with potential misclassification of exposure in epidemiological studies could lead to an underestimation of the true effect and thus an underestimation of the burden.

The approach to subdividing industry sectors into broad exposure groups, for example outdoor, mixed indoor/outdoor and mainly indoor for solar radiation, and allocating suitable risk estimates was a response to the lack of data on proportions exposed at different levels of exposure. Implicit assumptions were made regarding the similarity of durations and intensities of exposure between the population in the published study used for the risk estimates and British exposed workforce.

In most occupational epidemiological studies very short-term workers, e.g. those employed for less than a year, are excluded. Our turnover factor was thus calculated excluding workers with less than one year's employment. Inclusion of these would have increased the numbers ever exposed considerably. For example, for the construction industry, the annual turnover would increase from 13% excluding workers with under one year of employment to 22% when they are included. The overall effect of including these short-term workers would be to increase the AFs and attributable numbers.

There is a general paucity of information on latency of cancers due to occupational carcinogens, including solar radiation. Pragmatic assumptions about the length of the latency period were made and hence the risk exposure period.

A paper reporting exploration of the influence of these uncertainties is in preparation for submission to a scientific journal.

Summary

In summary, this project is the first to quantify in detail the burden of cancer due to occupational exposure to solar radiation specifically for Britain. The results highlight the importance of solar radiation exposure in several industry sectors and in particular, in the construction industry. These results, together with the results for NMSC, serve to emphasise the urgent need to develop appropriate strategies to reduce this burden. This could include minimising exposure between the hours of 12.00 and 15.00, wearing appropriate protective clothing and using suitable skin protection creams or lotions.

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7. Statistical Appendix

Formulae used in the estimation of AF by age group

Levin's equation to estimate attributable fraction (AF); risk estimate taken from an occupational study and proportion exposed taken from and independent source

$$AF = p(E)_g * (RR-1)/\{1+p(E)_g * (RR-1)\} \quad (1)$$

where RR = relative risk, $p(E)_g$ = proportion of the population exposed in age group g

A common denominator is used across exposure levels and industries for each exposure, by age group

Miettinen's equation to estimate attributable fraction; risk estimate and proportion exposed taken from a single occupational study

$$AF = p(E|D) * (RR-1)/RR \quad (2)$$

where p(E|D) = proportion of cases exposed (E = exposed, D = case)

Turnover equation to estimate numbers ever employed during the REP

$$N_{e(REP)\,g} = \sum_{i=a}^{i=b} l_{(adj15)i} * n_0/(R-15)\} + \sum_{k=0}^{k=(age(u)-age(l))} \sum_{j=c+k}^{j=d+k} \{l_{(adj15)j} * n_0 * TO/(age(u)-age(l)+1)\} \quad (3)$$

where $N_{e(REP)\,g}$ = numbers ever employed in the REP for age group g
n_0 = numbers employed in the exposed job/industry at a mid-point in the REP
TO = staff turnover per year
R = retirement age (65 for men and women)
$l_{(adj15)i}$ = the proportion of survivors to age i of those alive at age 15 (from GB life tables)
a to b = age range achieved by the original cohort members by the target year (2012) in age range g
c to d = age range achieved by the turnover recruited cohort members by the target year in age range g
age(u) and age(l) = upper and lower recruitment age limits (e.g. 44 and 15)

The derivation and assumptions underlying this formula are described in the methodology technical report, available on the HSE website (HSE 2011). The equation can be represented as a single factor acting as a multiplier for n_0, calculated by setting n_0 to 1 in the above equation, so that the factor varies only with TO see Table A1 below.

Equation to estimate the proportion of the population exposed

$$p(E)_g = N_{e(REP)\,g} / N_{p(REP)\,g} \quad (4)$$

where $N_{p(REP)\,g}$ = numbers ever of working age during the REP from population estimates for the relevant age group in the target year

Equation for combining AFs, by age group, where exposed populations overlap but are independent and risk estimates are assumed to be multiplicative:

$$AF_{overall} = 1 - \Pi_k(1-AF_k) \text{ for the k exposures in the set} \quad (5)$$

Table A1 Employment level adjustment factors and annual staff turnovers used in the calculation of AF

		Main Industry Sector	**Adjustment factor for change in employment levels***					**Turnover per year**
			1961-70	***1971-80***	***1981-90***	***1991-00***	***2001-10***	
Men	A-B	Agriculture, hunting and forestry; fishing	1.3	1.3	1.1	0.9	0.8	7%
	C-E	Mining and quarrying, electricity, gas and water; manufacturing industry	1.4	1.4	1.2	0.9	0.7	9%
	F	Construction	1.0	1.0	1.0	1.0	1.0	12%
	G-Q	Service industries	0.8	0.8	0.9	1.0	1.2	11%
		Total						10%
Women	A-B	Agriculture, hunting and forestry; fishing	1.2	1.2	1.1	1	0.9	10%
	C-E	Mining and quarrying, electricity, gas and water; manufacturing industry	1.5	1.5	1.2	0.9	0.6	14%
	F	Construction	0.9	0.9	0.9	1.0	1.1	15%
	G-Q	Service industries	0.7	0.7	0.9	1.1	1.2	15%
		Total						14%

* Applied to CAREX data for the solid tumour REP only.

8. Supplementary Table

Table 6a Results for Cutaneous Malignant Melanoma and Exposure to Occupational Solar Radiation using an 'all age' attributable fraction estimator and assuming that workers enter the exposed cohort between the ages of 15 and 24

	Men	Women	Total
Numbers ever exposed	3,670,413	1,903,484	5,573,897
Proportion of the population exposed	17.65%	8.57%	12.96%
Malignant Melanoma			
Attributable Fraction	2.93%	0.88%	1.88%
Attributable deaths (2012)	36	8	44
Attributable registrations (2011)	170	54	224
Years of Life Lost	591	144	735
Disability-adjusted Life-years	744	195	939

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