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Firefighters and cancer: the epidemiological evidence

TM/17/01

March 2020

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Firefighters and cancer: the epidemiological evidence

Joanne O. Crawford, Thomas Winski, Richard Graveling, Ken Dixon, Hilary Cowie, Damien McElvenny.

It is recognised that firefighters can be exposed to many different harmful substances. In 2007 the International Agency for Research on Cancer convened a working group to assess the carcinogenicity of a variety of occupations, and increased rates of testicular and prostate cancer and non-Hodgkin's lymphoma were identified for firefighting. This report examines the research published since an IOM review for the UK Industrial Injuries Advisory Council, by carrying out a systematic review and meta-analyses of the epidemiological evidence for specific cancers in firefighters. In total 304 publications were screened against the inclusion criteria, 261 publications were excluded based on their title/abstract and a further 20 were excluded once the full publication had been examined. The remaining 23 papers were included in the review. Meta-analyses were carried out for 18 specific cancer sites. Cancers identified as having a positive association with firefighting were colon (meta-RR 1.21, 95% CI 1.11-1.31), rectal (1.15, 1.04-1.27), melanoma (1.39, 1.27-1.52), prostate (1.15, 1.05-1.26), bladder (1.15, 1.02-1.30) and non-Hodgkin's lymphoma (1.13, 1.04-1.23). The report highlights that a number of cancers were identified as having a raised risk among firefighters, but there was no evidence in this literature of the association found previously with testicular cancer. Examination of the exposures associated with these cancers, to which firefighters may be exposed, showed that Polycyclic Aromatic Hydrocarbons (PAHs) were associated with melanoma, bladder and possibly prostate cancer and diesel exhaust fumes with prostate and bladder cancer and possibly non-Hodgkin's lymphoma. Exposure to a variety of PAHs in live firefighting, training exercises, wildfire firefighting, overhaul and within fire station engine bays. This exposure could be mitigated through frequent cleaning of kit and assessment of the structural design of fire stations.

Report for:

Kingspan

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Third party disclaimer

Document revisions

No	Details	Date

This report including the front and back page contains 117 pages

Contents

Index of Tables

Index of Figures

Summary

It is recognised that firefighters are exposed to a variety of harmful substances and physical agents, and there has been a growing body of research in the last decade in relation to cancer occurrence within this occupational group. In 2007 the International Agency for Research on Cancer (IARC) convened a working group to assess the carcinogenicity of a variety of occupations including firefighting. This working group identified increased risks for three types of cancer – testicular and prostate cancer and non-Hodgkin's lymphoma. Exposure assessment for this group has been difficult, including the reliable quantification of exposure. The current report is of a three-phase study that (i) examined the research published since a 2010 review carried out by the IOM for the Industrial Injuries Advisory Council (IIAC), by carrying out a systematic review and meta-analyses of the epidemiological evidence for specific cancers in firefighters, (ii) examined the occupational exposures associated with the cancers identified in Phase 1 and whether these exposures occurred in firefighters and (iii) looked in more detail at the potential exposure of firefighters to polycyclic aromatic hydrocarbons (PAHs) as these were the most commonly identified potentially causal exposures in Phase 2.

Phase 1

The first stage of the research was the development of a search strategy and carrying out searches between April and May 2016. In total 304 publications were screened against the inclusion criteria and 261 publications were excluded. From the 43 full publications sourced, eighteen were excluded as not being relevant to the review and two duplicate papers were identified. The resulting 23 papers were included in the review.

Meta-analyses were carried out for 18 specific cancer sites. Cancers identified as having a positive association with firefighting were colon (meta-RR=1.21, 95% CI 1.11-1.31), rectal (1.15, 1.04-1.27), melanoma (1.39, 1.27-1.52), prostate (1.15, 1.05-1.26), bladder cancer (1.15, 1.02-1.30) and Non-Hodgkin's lymphoma (1.13, 1.04-1.23).

Firefighters are exposed to a large number of hazards and the types of exposure depend on what is being combusted or which chemical has been spilled. While positive associations have been identified in one country, this has not necessarily been reflected internationally. There can be many explanations for this, including variations in risk amongst the comparator populations and differences in hazard exposures between firefighters in different countries reflecting different firefighting strategies. While exposure assessment has been difficult in this area of research, reliably quantifying exposure is also difficult. Data from other comparable groups were not of a high enough quality to allow a reasonable comparison.

The report identifies firefighters as having an elevated risk of a number of cancers compared to the general population. These comprise colon cancer, rectal cancer, melanoma, prostate, bladder and

Non-Hodgkin's lymphoma. However, the analysis of data for testicular cancer did not affirm the increased risk identified by some earlier analyses. No association was found between lung cancer and firefighting, however one study of Danish firefighters did report a significant association with lung adenocarcinoma.

Phase 2

The occupational risk factors associated with the six cancers identified in Phase 1 were examined and consideration given to whether these risk factors are present for firefighters, who are involved in firefighting in a range of situations, within buildings, woodland fires, vehicle extrications and in the USA, also take on the dual role of being a paramedic. The data also represents an international perspective and it should be borne in mind that there are different work practices, different levels of protection and different work processes between national borders. IARC (2010) suggest that the time spent by a firefighter actually involved in fires is between 0.75% and 2.7% of their working time over the course of a year.

The approach taken was to examine the factors that the research literature indicates are linked to the development of specific forms of cancer and to examine whether firefighters are exposed to these risk factors. The study takes into account evidence regarding the known hazards to which firefighters are exposed, drawn from the existing research literature and from other reputable data sources, including the International Agency for Research into Cancer, Cancer Research UK, the National Institutes for Cancer (USA) and Australian cancer data sources. The collective evidence from these various sources was used to assess the likelihood of occupation as a firefighter being a cause of the specific cancers examined.

Firefighters are potentially exposed to many different substances in the work that they do. However, it is clear that the nature and extent of such exposures varies tremendously between individuals and, as a result, it is difficult to identify particular exposures in respect of cancer causation. The causes of most cancers are multifactorial, often including both lifestyle factors (such as smoking and diet), as well as occupational factors not related to substance exposure such as shift work or having a second job, in addition to any arising from substance exposures during firefighting activities, chemical spillages, etc. Given the relatively modest nature of any elevated risk identified it is likely that the contribution of exposure to any particular chemical substance is likely to be even more modest.

Nonetheless, the study found that there are known associations between PAHs and melanoma, bladder and possibly prostate cancers. However, the sources of PAHs in any fire environment can be numerous and without specific environmental monitoring it is impossible to state the sources. Exposure to diesel fumes was also identified as being associated with prostate and bladder cancer and possibly associated with non-Hodgkin's lymphoma and lung adenocarcinoma.

Phase 3

For the third phase of the study, we looked in more detail at the potential exposure of firefighters to PAHs as these were the most commonly identified potentially causal exposures. It should be noted that it is likely that all burning substances that contain aromatic compounds (including, but not limited to, building materials, furnishings, trees and vehicles) will emit PAHs. In addition, the sources of PAHs in any fire environment can be numerous and without specific environmental monitoring it would not be possible to identify these sources. The nature of fires in terms of the substances burning and consequential exposures to potentially toxic combustion products will have changed over time, with new building materials, building furnishings and contents and an increased use of plastics and other man-made materials.

The Phase 3 work aimed to examine the following research questions: (i) what sources of PAHs are firefighters exposed to, (ii) what is the route of exposure for firefighters and (iii) what assessments have been made in relation to materials and combustion? These questions were addressed through identification of the relevant literature, identification of exposure routes and measurements and identification of relevant research into materials and combustion.

The research reviewed confirmed that firefighters are exposed to a variety of PAHs in live firefighting, training exercises, wildfire firefighting, overhaul and within fire station engine bays. There also appears to be ingress into fire engines and office and dormitory areas in fire stations. However, the types of PAHs monitored in each of these settings varied and not all were grouping 1 in the IARC classification.

How often firefighters' kit is thoroughly cleaned also warrants discussion. It was reported that by carrying out decontamination on site, 85% of contaminants were removed and it was suggested that fire kit should be washed after every fire event. The results from the studies reviewed suggest that there is also a need to improve fire kit removal procedures. There is certainly experience in emergency service workers in the safe donning and doffing of PPE for chemical or nuclear exposure. Research should be carried out to examine the best means of removing fire kit and in which order to ensure contamination is kept to a minimum.

Structural design issues within fire stations were also highlighted as part of this review to reduce exposure to PAHs. A number of international studies identified building age and design as a factor. From these studies there needs to be a better separation of engine and equipment bays from office and domestic areas. Ventilation equipment is also available for use when engines are started, but this may not always be used effectively.

Phase 1 – Firefighters and cancer: the epidemiological evidence

1 Phase 1: Introduction

It is recognised that firefighters are potentially exposed to a variety of harmful substances and physical agents, and there has been a growing body of research in the last decade in relation to cancer occurrence within this occupational group.

In 2007, the International Agency for Research on Cancer (IARC) convened a working group to assess the carcinogenicity of painters, shiftworkers and firefighters. From this, a summary publication (Straif *et al.,* 2007, IARC 2007) indicated that firefighters are exposed to many toxic combustion products, including many known, probable or possible carcinogens. As part of their deliberations, the working group updated the meta-analysis of LeMasters *et al.,* (2006), concluding that, although consistent patterns of risk were difficult to discern (partly due to the wide variability in exposure between different firefighter populations in different countries), they were satisfied that for three types of cancer the relative risks were consistently and significantly increased. For testicular cancer all six studies identified showed increased risks (average relative risk [ARR] 1.5); for prostate cancer 18 of 21 studies showed increased risks (ARR 1.3); and, for non-Hodgkin's lymphoma increased risks were identified in five of six studies (ARR 1.2) (Straif *et al.,* 2007).

There has been considerable difficulty in reliably quantifying exposures making exposure assessment very difficult. It was additionally noted that the acute and chronic inflammatory respiratory effects found in firefighters would provide a plausible mechanism for respiratory carcinogenesis. The IARC working group concluded by classifying occupational exposure as a firefighter as *"possibly carcinogenic to humans" (Group 2B).*

Other epidemiological evidence has since emerged which appears to strengthen the apparent connection between working as a firefighter and some forms of cancer. For example, Kang *et al.,* (2008) reported increased Standardised Morbidity Odds Ratios (SMORs) for colon cancer (SMOR = 1.36, 95% CI: 1.04–1.79), and brain cancer (SMOR = 1.90, 95% CI: 1.10–3.26).

In 2010, Graveling and Crawford published a review for the UK Industrial Injuries Advisory Council (IIAC) on Occupational Health Risks in Firefighters (Graveling and Crawford, 2010). This review examined 23 cancer sites and examined the relative risk of each of the cancers in relation to the occupation of firefighter. The remit of this particular review was to identify whether there was robust evidence for at least a doubling of risk within the firefighter population in relation to particular cancers, as any such cancer might then be recommended for classification as a prescribed industrial disease within the UK. Although a doubling of risk was not identified in any of the 23 cancer sites examined, estimated risks relative to the general population based on qualitative assessment of the cumulative evidence were found to be higher than 1.0 for colon, skin, prostate, testicular and breast cancer.

While the cancer risks to firefighters have been previously examined, these should be put into context within the general population. As an occupation, firefighters require specific fitness standards to be achieved on entry and, in some countries, throughout their working life. This has led to suggestions of a "healthy worker survivor effect" that describes a continuing selection process such that those who remain employed tend to be healthier than those who leave employment. Chronic diseases in older age are less likely to occur in firefighters compared to the general population. For example, a study of US firefighters found a decrease in risk of stroke (9% less likely) and diabetes (28% less likely) amongst firefighters while some risks were increased such as colon cancer (31% more likely) or kidney cancer (29% more likely). (Daniels *et al.*, 2013 quoted in Dow *et al.*, 2015).

It is recognised that firefighters are exposed to certain types of environments during firefighting and overhaul (cleaning up). These environments include different types of fires including buildings or forest fires as well as dealing with motor vehicle accidents and extrication of people from vehicles. Several of these tasks are known to cause exposure to substances hazardous to health; although Personal Protective Equipment (PPE) and Respiratory Protective Equipment (RPE) are provided in the majority of cases. However, when examining all-cause mortality of different occupational groups, Harris *et al.*, (2016) found in the UK that there was a 25% reduction in the number of deaths from all causes in fire service personnel between 1979 and 2010 in England and Wales. This reduction may be due to improved safety, but it may also reflect reductions in the numbers of men employed in firefighting, and falling mortality from some diseases across the whole population.

The data used in previous studies of cancer and firefighting typically used the general population as the comparator when analysing the incidence data from cancer registries or mortality data including cancer mortality from national death registries. Thus, where an increase or decrease is identified within the firefighting population, this is in comparison to what would be expected within the general population.

Table 1 Lifetime risk of specific cancers in the general population (UK data for 2012)

Cancer	Lifetime risk (Female)	Lifetime risk (Male)
Melanoma	1.85%	1.94%
Bladder	0.95%	2.62%
Brain	1.37%	1.35%
Breast	12.99%	0.12%
Bowel	5.47%	7.27%
Kidney	1.15%	1.96%
Leukaemia	1.07%	1.61%
Lung	6.17%	7.76%

Myeloma	0.66%	0.89%
NHL	1.73%	2.12%
Oesophagus	0.90%	1.85%
Pancreas	1.38%	1.44%
Prostate		13.72%
Stomach	0.76%	1.51%

Source Cancer Research UK: http://www.cancerresearchuk.org/health-professional/cancer-statistics/risk/lifetime-risk#heading-One. Accessed October 2016

Table 1 presents the lifetime risk from birth of getting a particular cancer in individuals in the UK general population. However, an individual's cancer risk is dependent on several factors including genetic make-up, age, and exposure to environmental carcinogens; including lifestyle factors such as smoking and diet. For example, the lifetime risk of lung cancer among individuals who smoke tobacco is 15.9% in males and 9.5% for women. Comparing that to Table 1, which includes both smokers and non-smokers, shows that lung cancer risks in non-smokers are much lower than the risks presented of 6.2% and 7.8%, respectively.

Assessment of epidemiological research on cancer in firefighters should not include assumptions based solely on the potential carcinogens to which firefighters are exposed. For example, previous research in firefighters has identified that there is no excess risk of lung cancer in firefighters, potentially due to the protection afforded by consistent use of breathing apparatus and other PPE. By using PPE, firefighters will not come into contact with chemicals, dust and fumes to the same extent as they might otherwise do without the use of PPE. Nevertheless, surrogates for cumulative exposure such as duration of employment can be used to provide crude indications of risk in relation to cumulative exposure to work as a fire-fighter.

Other important factors, which are difficult to take into account when analysing and interpreting studies, are the long latency period for many cancers and the implicit assumption that exposure to risk as a firefighter has remained constant throughout that time. This assumption is not necessarily valid. In many countries, the protection worn by firefighters (including the more routine use of Breathing Apparatus (BA) and fire hoods) has improved considerably over a period of about 30 years, which will have reduced the extent of exposure to hazardous materials. However, to offset this, the nature of fires in terms of the substances burning and consequent exposures to potentially toxic combustion products will also have changed, with new building materials, building furnishings and contents and an increased use of plastics and other man-made materials.

The aim of the following report is to examine the research published since the 2010 review for IIAC, by carrying out a systematic review of publications since that date on the epidemiological evidence for specific cancers in firefighters. Furthermore, a meta-analysis has been carried out that examines all data, not just that published since 2010.

2 Phase 1: Methodology

The research question addressed by the review is:

1. What is the epidemiological evidence of the incidence of or mortality from specific cancers in firefighters, and how does this compare to other relevant occupational groups?

A search strategy was developed and is available in Appendix 1. Searches were carried out between April and May 2016. The review by Graveling and Crawford, (2010) examined 23 different cancers. As this work is one of the most recent systematic reviews with regard to cancer and firefighters, it has been used as a starting point when examining research carried out since 2009.

In total, 304 references were identified from the searches. The title and abstract (where available) for the references were screened against the inclusion criteria (listed in Appendix 1). This resulted in the exclusion of 261 papers which did not meet the inclusion criteria.

The next stage of evaluation for the papers was completed after receipt of the full papers. From the 43 papers, eight were excluded as not meeting the inclusion criteria. The papers and the reasons for exclusion are presented in Appendix 2. Two duplicate papers were identified and eight papers were identified as being relevant for inclusion in later work packages. Data extraction was carried out for each of those papers using the Scottish Intercollegiate Guidelines Method (SIGN 2014).

For those 25 papers included in the review, 23 examined firefighters and two were on police and criminal investigators (these were subsequently excluded). The papers included for firefighters comprised three case-control studies, 12 cohort studies, two systematic reviews, five narrative reviews and one opinion/editorial. The papers are summarised in Appendix 3.

Meta-analysis was carried out using the statistical package Stata version 13 (Statcorp, 2013). Fixed effect meta-analyses were carried out in the absence of statistically significant heterogeneity and random effects meta-analyses when significant heterogeneity was present (Der Simonian & Laird 1986). Where there was a choice of risk estimate to include in the meta-analysis, incidence data were preferred to mortality data, risk estimates that were based on first primary cancer were preferred to those based on all primary cancers, and risk estimates based on individuals who were employed for 12 months or more were preferred to those based on all workers. A decision was made to see if there was a trend in findings by publication year. Hence, studies were examined separately before and after the median year of publication in 2000. We have used the following formula to calculate the standard error of the log of the relative risk:

$$Se(logrr) = (log(u95cl)-log(l95cl))/3.92$$

We are aware that the main reason for carrying out a meta-analysis is to explore heterogeneity of study results (e.g. Greenland 1987) in order to understand why different studies might be producing different results. Meta-analyses should contain sensitivity analyses to assess the robustness of any findings and should also contain an assessment of the risk of bias. Further exploration of these issues and other expected aspects of meta-analysis may be completed during a later phase of this work. In essence, this work is essentially hypothesis-generating and any excesses found for certain cancers will need to be tested for robustness in more detailed analysis, including, where possible, assessment of exposure-response.

3 Phase 1: Results

3.1 Cancer overall

Several papers calculated the risk of cancer among firefighters as an occupation and the incidence of all cancers combined in this group. Daniels *et al.,* (2013) identified a standardised incidence ratio (SIR) compared to the general population of 1.09, 95% CI 1.06-1.12 for all forms of cancer in US firefighters. Glass, (2009), when researching Australian firefighters identified an SIR=1.00, 95% CI 0.84-1.20, and Pukkala *et al.,* (2014) in their study of Nordic firefighters identified an SIR=1.1, 95% CI 1.02-1.11, again in each case for all forms of cancer. Zeig-Owens *et al.,* (2011) carried out analysis of the firefighters involved in the rescue and recovery during the 9/11/01 World Trade Center (WTC) incident and found an SIR for all cancers in all firefighters of 1.10, 95% CI 0.98-1.25 and SIR=0.84, 95% CI 0.71-0.99 for firefighters not exposed to WTC dust. These data give a mixed picture internationally in relation to cancer incidence among firefighters compared to the general population.

Mortality rates have also been examined. Two studies from Korea, (Ahn *et al.,* 2012, Ahn and Jeong, 2015), identified standardised mortality ratios (SMR) of 0.97, 95% CI 0.88-1.06 and 0.58, 95% CI 0.50-0.68. Ide (2014) carried out a cohort study of Scottish firefighters using reference populations from Scotland and the West of Scotland. The paper identified that for all cancers, the incidence in firefighters was significantly lower than in both the reference groups ($p<0.001$). The incidence rate for all cancers among firefighters was 86.5 cases per 100,000 in firefighters versus the reference populations of Scotland (123.7 per 100,000) and the West of Scotland (337.0 per 100,000). There were however substantial differences in the age distributions of the firefighters and the control groups.

These data suggest there are mixed results in relation to overall cancer incidence and mortality rates among firefighters and some evidence of a reduced risk of cancer mortality among firefighters. It is not possible to determine whether these differences reflect any substantive trend or national differences in risk. However, a clearer picture can be obtained when examining specific cancer sites for firefighters.

3.2 Specific cancers

The review by Graveling and Crawford, (2010) examined 23 different cancers. As this work is one of the most recent systematic reviews with regard to cancer and firefighters, it has been used as starting point for examining research carried out since 2009.

A decision was made to see if there was a trend in findings by publication year. Hence, studies were examined separately before and after the median year of publication in 2000. The aim of this was to look at any crude changes in the levels of reported relative risks over time and used 2000 as an arbitrary cut-off date representing an approximate median year of publication. However, it should be noted that some of the cohorts have included firefighters from 1925 through to 2011 and it is self-evident that working practices as well as protective equipment have changed since the 1920s. The split by publication date should therefore not be interpreted as representing data collected pre and post 2000.

3.2.1 Lip, oral (buccal) cavity and pharynx

The review by Graveling and Crawford (2010) identified a range of relative risks relative to the general population of between 1.0 and 1.1. Since this review, two further cohort studies have been published. Pukkala *et al.,* (2014) calculated cancer incidence in Nordic firefighters with an overall incidence rate of 0.8, 95% CI 0.4-1.3 for this cancer group. The research by Pukkala also examined in further detail cancer of the pharynx (SIR=1.0, 95% CI 0.60-1.57), cancer of the lip (SIR=0.8, 95% CI 0.46-1.28), cancer of the tongue (SIR=1.04, 95% CI 0.52-1.87) and cancer of the salivary glands (SIR=1.69, 95% CI 0.81-3.11). Daniels *et al.,* (2013) identified an SIR=1.41, 95% CI 1.20-1.66 for cancer in the pharynx and buccal area.

Two case-control studies also examined cancer of the oral cavity. Tsai *et al.,* (2015) examined cancer in Californian firefighters. The analysis identified that the odds ratio for lip cancer among firefighters was OR=1.44, 95% CI 0.89-2.33 compared to the control cancer cases (cancers unlikely to be associated with firefighting) who were firefighters. Further results examined cancer of the tongue (OR=1.18, 95% CI 0.82-1.70), cancer of the salivary glands (OR=1.30, 95% CI 0.75-2.25), cancer of the pharynx (OR=1.06, 95% CI 0.75-1.50) and cancer of the gum and other mouth (OR=1.07, 95% CI 0.62-1.85). The second study was Paget-Bailey *et al.,* (2013) as part of the French ICARE population-based research project. There were 13 firefighters within the cases and 12 within the control group. The odds ratio of head and neck cancer among firefighters compared with all other occupational groups was calculated as 3.9, 95% CI 1.4-11.2.

The majority of studies do not show an increased risk of head or neck cancer amongst firefighters with the exception of one study from a French working population, which showed an excess risk among firefighters and a strong statistically significant association with duration of employment. However, although difficult to elucidate the precise explanation for this apparent anomaly but the authors suggest that this could be due to exposure to fire smoke and hence a wide range of suspected carcinogens.

Due to the differences in types of cancers included in the research, a meta-analysis of the data was not performed.

3.2.2 Oesophageal cancer

The review of oesophageal cancer by Graveling and Crawford (2010) found a range of estimated risks relative to the general population of between 1.10 and 1.20. A study by LeMasters *et al.,* (2006) reviewed mortality and incidence of specific cancers among firefighters, and used the findings to produce a 'likelihood of cancer risk' based on the results of the reviewed studies, patterns across different studies, study type and study heterogeneity. Meta-relative risk for mortality based on 14 SMR studies was 0.68 (95% CI 0.39-1.08) and based on 1 relative risk study was 2.03, 95% CI 1.05-3.57. Meta-relative risk for 2 incidence studies was 1.32 (95% CI 0.63-2.42). The authors' overall 'likelihood of cancer risk' for oesophageal cancer was 'Unlikely' with a summary risk estimate of 1.16 (95% CI 0.86-1.57).

Since that date, four further cohort studies have been published that examined incidence rates in firefighters. Ahn *et al.,* (2012) analysed data from male professional emergency responders in Korea. As part of the analysis, a sub-set of firefighters (n=29453) was included. The analysis identified an SIR for oesophageal cancer for the firefighters of 0.75, 95% CI 0.28-1.64. The US study by Daniels *et al.,* (2013) identified an SIR=1.71, 95% CI, 1.36-2.13; with Pukkala *et al.,* (2014) calculating an SIR=0.98, 95% CI 0.66-1.39. Zeig-Owens *et al.,* (2011), calculated separate SIRs for firefighters exposed to dust from the World Trade Center collapse and those not exposed to this dust. This study identified an SIR of 0.58, 95% CI 0.15-2.32 among exposed firefighters and SIR=0.44, 95% CI 0.06-3.13 among non-exposed firefighters.

The one case-control study included in this review identified that compared to the proportion of control cancer cases (cancers unlikely to be associated with firefighting) who were firefighters, the odds ratio for oesophageal cancer among Californian firefighters was OR=1.59, 95% CI 1.20-2.09 (Tsai *et al.,* 2015).

These data show diverse results in relation to firefighting and oesophageal cancer depending on the national source of the data. To quantitively summarise these data in more detail, a meta-analysis of studies which included relative risks of oesophageal cancer was carried out. The analysis included data from the following papers: Ahn et al 2012, Aronson *et al.,* 1994, Baris *et al*., 2001, Bates et al, 2001, Bates et al, 2007, Beaumont *et al.,* 1991, Daniels et al, 2013, Demers *et al.,* 1994, Kang *et al.,* 2008, Ma *et al.,* 2006, Pukkala et al, 2014, Vena & Fiedler.,1987, and Zeig-Owens et al 2011.

The meta-analysis identified, using the fixed effect model, a meta-RR=1.19, 95% CI 1.05-1.35 was found in the presence of significant heterogeneity (p<0.001). Using a random effects model, the meta-RR=1.03, 95% CI 0.76-1.38.

Comparison was made between papers published pre 2000 and post 2000 to examine any difference between reporting periods. This is presented in Figure 1. For studies published before 2000 a random effects meta-RR=1.48, 95% CI 0.87-2.53 was calculated versus a meta-RR=0.95 95% CI 0.67-1.34 for studies published in 2000 or later. There is some indication that the RR was lower in more recent studies, but the difference was not significant. Overall there is no evidence that oesophageal cancer risk is increased in fire-fighters.

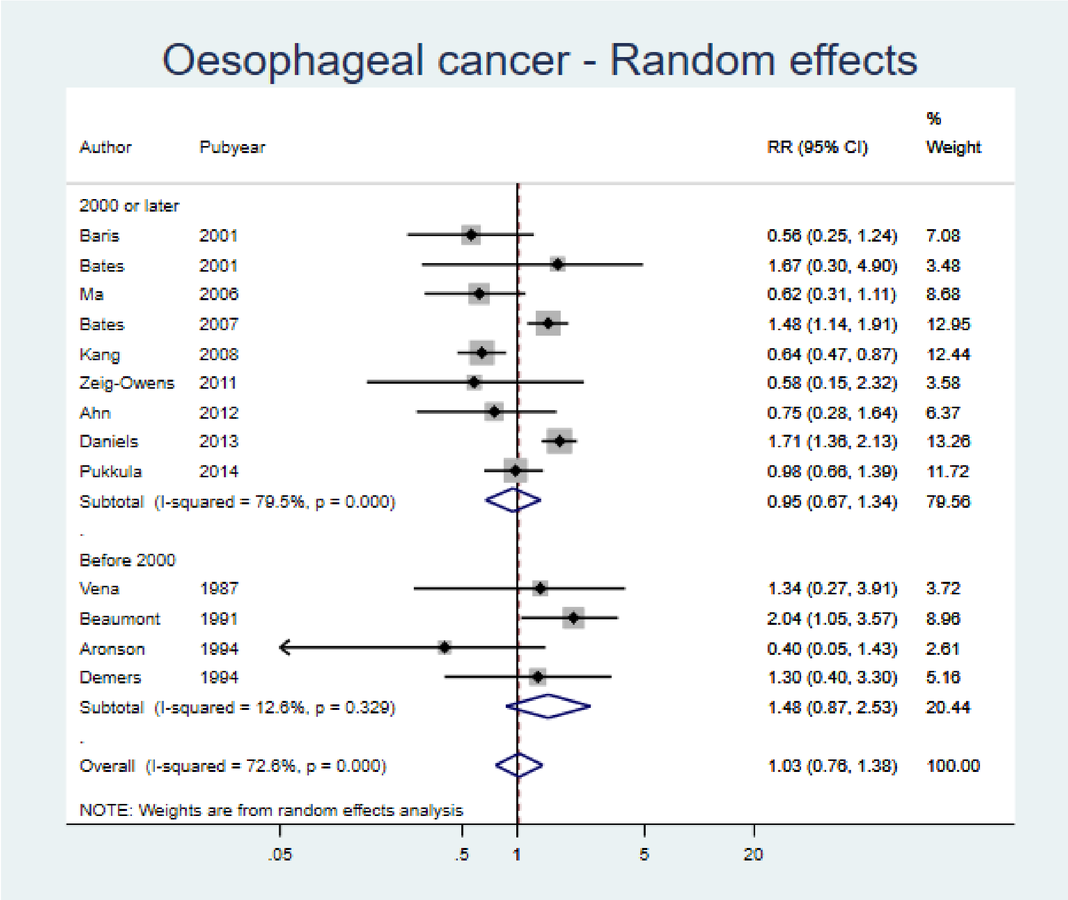

Figure 1 Forest plot for Oesophageal Cancer papers published pre 2000 and post 2000[1]

3.2.3 Stomach Cancer

The review by Graveling and Crawford (2010) estimated a risk relative to the general population for stomach cancer as being close to 1. In updating this review, the cohort studies included both standardised incidence ratios (SIR) and standardised mortality rates (SMR) both of which attempt to estimate relative risk. For stomach cancer, the following ratios were identified, an SIR=1.09, 95% CI 0.91-1.30 (Pukkala *et al.*, 2014), an SMR=0.63, 95% CI 0.43-0.88 (Ahn and Jeong, 2015), SIR=1.02, 95% CI 0.80-1.28 (Daniels *et al.*, 2013) and an SIR=2.24, 95% CI 0.98-5.25 for firefighters exposed to WTC dust and SIR=1.23, 95% CI 0.40-3.83 for non-exposed firefighters (Zeig-Owens *et al.*, 2011). In their case-control study, Tsai *et al.*, (2015) did not show a significant difference in cancer incidence between cases and controls with a calculated OR=0.81, 95% CI 0.59-1.11.

The data included do not show an association between stomach cancer and firefighting. However, to quantitatively summarise these data in more detail, a meta-analysis was carried out including the papers by Ahn & Jeong 2015, Aronson *et al.*, 1994, Baris *et al.*, 2001, Bates 2001, Bates, 2007, Beaumont *et al.*, 1991, Daniels et al, 2013, Demers *et al.*, 1994, Donnan, 1996, Eliopulos et al, 1984,

[1] Minor discrepancies in numbers between the plot and the report are due to rounding

Grimes et al 1991, Guidotti 1993, Kang *et al.*, 2008b, , Ma *et al.*, 2006, Pukkala et al 2014, Tornling *et al.*, 1994, Vena and Fiedler, 1987, Zeig-Owens et al 2011.

The meta-analysis for fixed effects identified a meta-RR=0.99 95% CI 0.90-1.09 and there was no significant heterogeneity (p = 0.112). There was no association between stomach cancer and firefighting.

When comparing studies published before 2000 versus those published post 2000, the fixed effect meta-analysis produced a meta-RR=1.04, 95% CI 0.82-1.32 for those published pre 2000 and meta-RR=0.98 95% CI 0.88-1.09 post 2000; neither of which show a significant association. These data are presented in Figure 2 below.

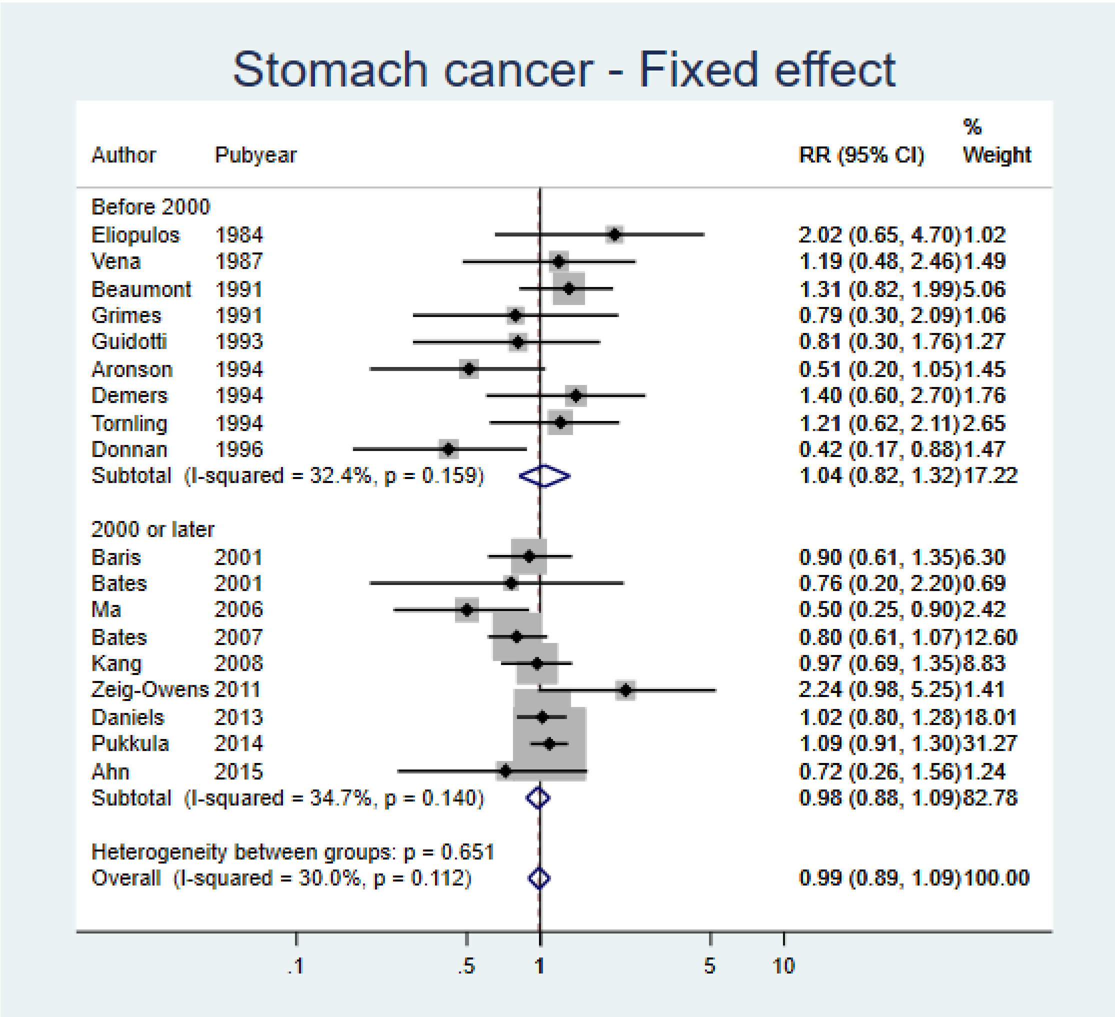

Figure 2 Forest plot for Stomach Cancer papers published pre 2000 and post 2000

3.2.4 Colorectal, Colon and Rectal Cancer

When reviewing the papers in relation to colon, colorectal and rectal cancer it was noted that differences in the descriptions used for these cancers made it difficult to discern which cancers were under discussion in which papers. As a result of this, the papers were reviewed and examined in relation to colon cancer, colorectal cancer and rectal cancer, where these were reported separately in the included publications.

From the 2010 review, thirteen papers were included that examined colon cancer and this resulted in an estimated risk relative to the general population of 1.2 (Graveling and Crawford, 2010). In the meta-analyses by LeMasters *et al.,* (2006) an association was found for colon cancer with a summary risk estimate of 1.21, 95% CI 1.03-1.41. Since that review, five cohort studies of colon cancer have been published internationally, with marginal significance identified for two studies. These included the research by Fang *et al.,* (2011), in a Canadian population based case-control study of colon cancer where the odds ratio for those who ever worked as a firefighter was calculated as OR=0.95, 95% CI 0.40-2.25 and among those whose usual job was a firefighter was 1.14, 95% CI 0.50-2.60. Glass, (2009), calculated a standardised incidence ratio (SIR) for colorectal cancer of 0.85, 95% CI 0.49-1.46 in Australian full time firefighters and Pukkala *et al.,* (2014), calculated an SIR for colon cancer of 1.14, 95% CI 0.99-1.31 in Nordic firefighters. Data from Korea identified a standardised mortality ratio for colorectal cancer of 0.65, 95% CI 0.34-1.14 (Ahn and Jeong, 2015).

The paper by Ide, (2014), examined cancer in Scottish firefighters between 1985 and 2004. He identified that for colon cancer, there was significantly lower incidence within the firefighting group (9.1 cases per 100,000) compared to 13.8 cases per 100,000 in the reference population ($p<0.01$), although this could be due to the age differences between the two groups. Finally, Zeig-Owens *et al.,* (2011) calculated an SIR for colon cancer of 1.52, 95% CI 0.99-2.33 in the firefighters exposed to WTC dust and SIR=1.01, 95% CI 0.53-1.94 in unexposed firefighters.

The one case-control study included in this study identified a similar pattern where risk estimates by Tsai *et al.,* (2015), resulted in an OR for colorectal cancer of 1.1, 95% CI 0.93-1.31 for firefighters compared to the proportion of control cancer cases (cancers unlikely to be associated with firefighting) who were firefighters.

In comparing the results within these papers, it should be noted that different definitions were used with some papers analysing colon cancer and others analysing colorectal cancer.

To examine the reported relative risks of colon cancer, colorectal cancer and colon cancer, a meta-analysis was carried out using data from the current papers cited as well as those from the 2010 review: Ahn & Jeong 2015, Aronson *et al.,* 1994, Baris *et al.,* 2001, Bates *et al.,* 2001, Beaumont et al 1991 (colon plus small intestines), Burnett et al 1994, Daniels et al 2013, Demers *et al.,* 1994, Donnan, 1996, Eliopulos et al 1984 (colon plus small intestines), Fang et al 2011, Giles et al, 1993, Glass et al, 2009, Grimes *et al.,* 1991, Guidotti, 1994, Kang et al 2008, Ma *et al.,* 2006, Pukkala el al, 2014, Sama *et al.,* 1990, Tornling *et al.,* 1984, Vena and Fiedler, 1987, and Zeig-Owens et al, 2011.

The meta-analysis combined colon, colorectal and rectal cancer as well as analysing each cancer separately.

The fixed effect meta-RR for colon, colorectal and rectal cancer combined was equal to 1.13, 95% CI 1.08-1.19 (p=0.004 for heterogeneity). The random effects meta-RR was 1.14 (95% CI: 1.05 to 1.24) which was marginally statistically significantly elevated.

Within the Graveling and Crawford (2010) review, data on rectal cancer was examined. Although many of the risk estimates were not statistically significantly different to 1.0, the estimated risk relative to the general population showed a relatively modest association of less than 1.3. LeMasters *et al.,* (2006) in their meta-analysis concluded that there was a 'possible' likelihood of cancer risk for rectal cancer among firefighters with a summary risk estimate of 1.29, 95% CI 1.10-1.51.

In examining more recent cohort studies, Daniels *et al.,* (2013) identified an SIR of 1.11, 95% CI 0.95-1.30 in US firefighters and an SMR=1.45, 95% CI 1.16-1.78 and Pukkala *et al.,* (2014) identified an SIR=0.99, 95% CI 0.82-1.19 for rectal cancer.

The results identified here from cohort and case-control studies agree with previous studies where there was an association identified between rectal cancer and occupation.

Examining colon, colorectal, and rectal cancer separately in a random effects meta-analyses gave meta-RRs for colorectal cancer of 0.90 (95% CI: 0.70 to 1.17), for colon cancer of 1.21 (95% CI: 1.11 to 1.31) and for rectal cancer of 1.15 (95% CI: 1.04 to 1.27). These results are shown in Figure 3 below.

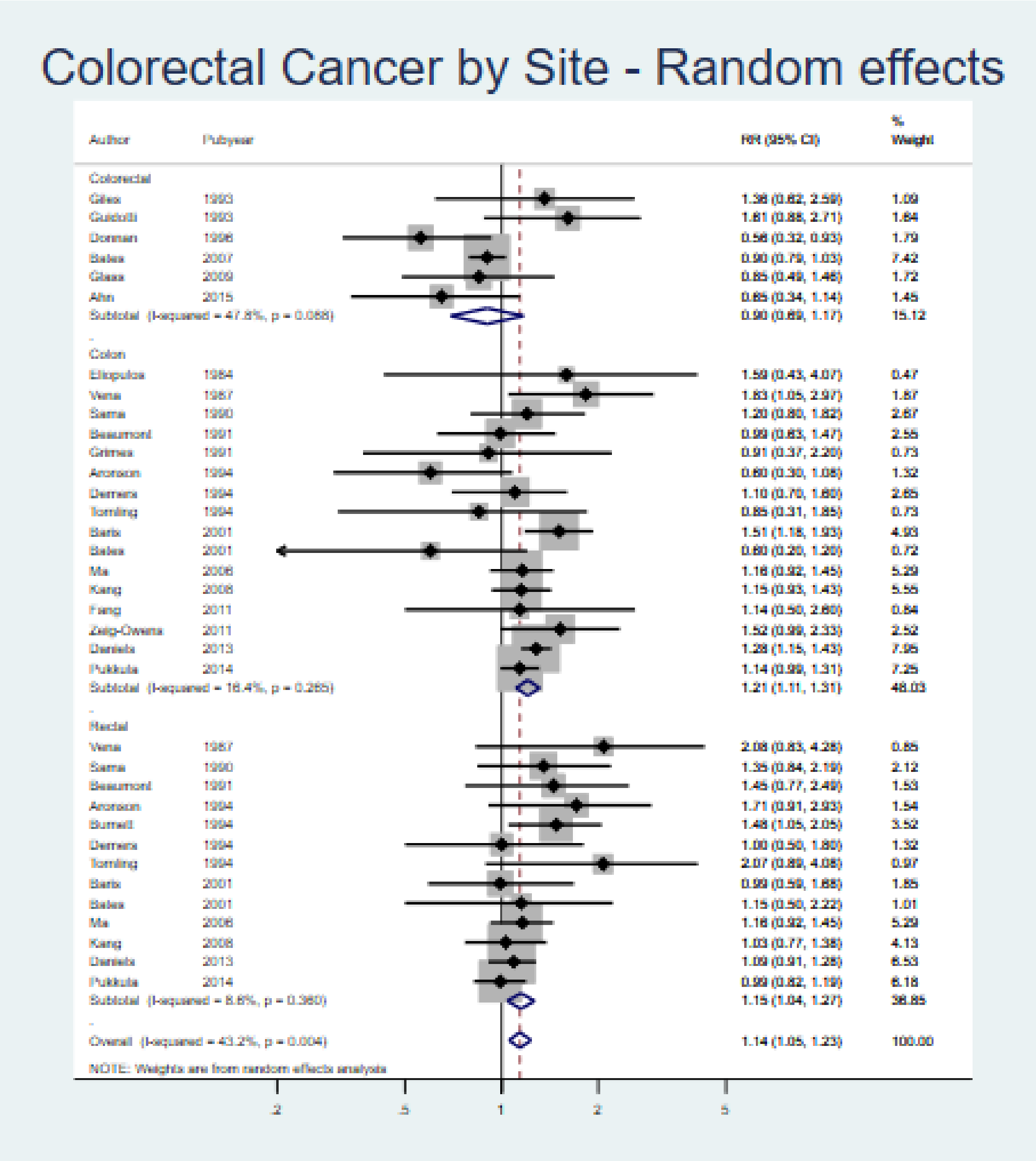

Figure 3 Forest plot for Colorectal Cancer meta-RRs by cancer site

For all results combined published before 2000 the random effect meta-RR was 1.23 (1.04 to 1.45) and for those published in 2000 or later was 1.11 (1.02 to 1.21) suggesting no difference due to century of publication. These data are presented in Figure 4 below by whether published before 2000 or not.

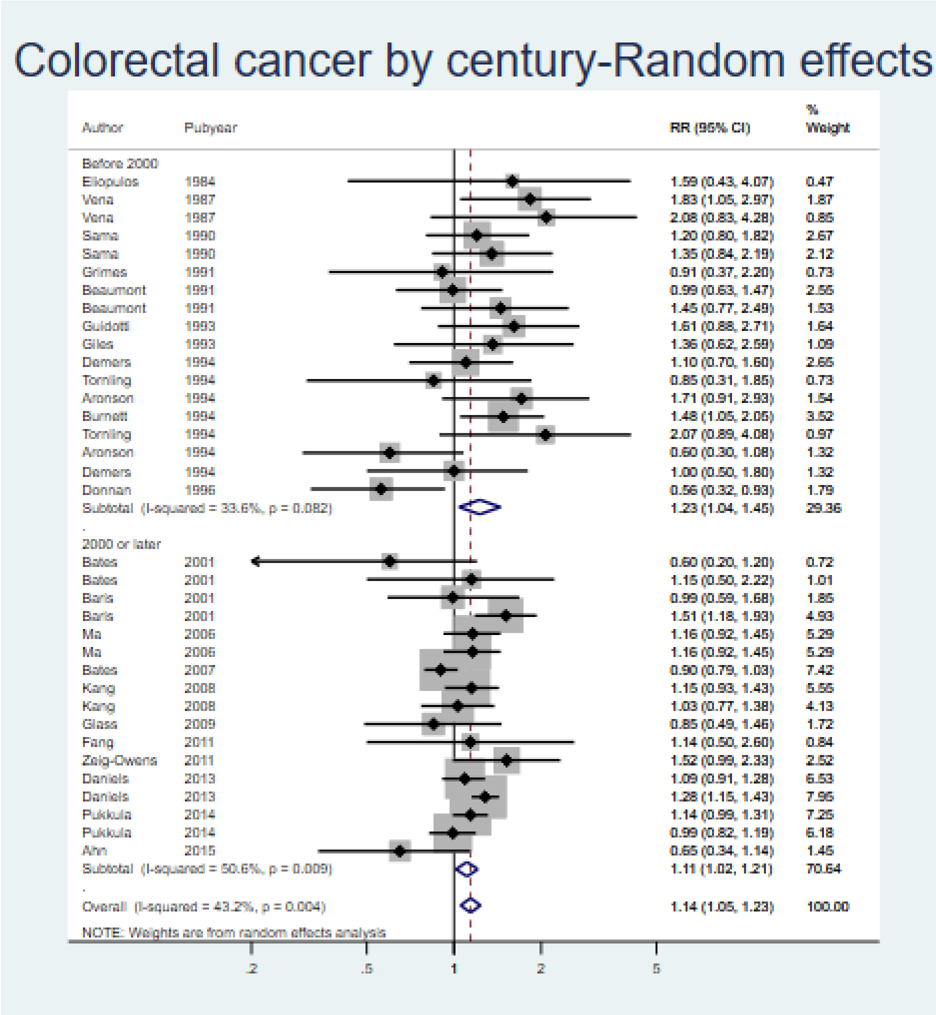

Figure 4 Forest plot for Colon, Colorectal and Rectal Cancer papers published pre 2000 and post 2000

3.2.5 Pancreatic Cancer

The review by Graveling and Crawford (2010) did not identify any raised risks for pancreatic cancer among firefighters compared to the general population. The meta-analysis by LeMasters *et al.,* (2006) found the same. This pattern has continued with the cohort studies included in this review where none of the studies showed a statistically significant excess. For example. Glass (2009) among men who were ever employed as a full-time firefighter had SIR= 1.45 95% CI 0.47–4.49, Pukkala *et al.,* (2014) with SIR=1.17 95% CI 0.94-1.45, Zeig-Owens *et al.,*(2011), SIR= 2·52 95% CI 0·28–22·59 and Ahn *et al.,* (2012) with an SIR=0.95, 95% CI 0.44-1.81. A similar result was found for the case-control study by Tsai *et al.,* 2015, where an odds ratio of 1.10 (95% CI 0.83-1.46) was calculated.

A meta-analysis was carried out using these data and data from the 2010 review including Ahn et al 2012, Aronson *et al.,* 1994, Baris *et al.,* 2001, Bates *et al.,* 2001, Bates et al , 2007, Beaumont *et al.,* 1991, Demers *et al.,* 1994, Giles *et al.,* 1993, Glass et al 2009, Guidotti, 1993, Kang *et al.,* 2008b, Ma *et al.,* 2006, Pukkala et al 2014, Sama *et al.,* 1990, Tornling *et al.,* 1994, Vena and Fiedler, 1987, Zeig-Owens et al 2011.

For the fixed effects model, a meta-RR=1.02, 95% CI 0.90-1.15 (p=0.781) was calculated.

When comparing publications pre and post 2000, a pre-2000 meta-RR=1.18, 95% CI 0.89-1.57 was calculated and a meta-RR=0.99, 95% CI 0.86-1.12 post 2000. These data suggest that pancreatic cancer rates in firefighters are not higher than the general population.

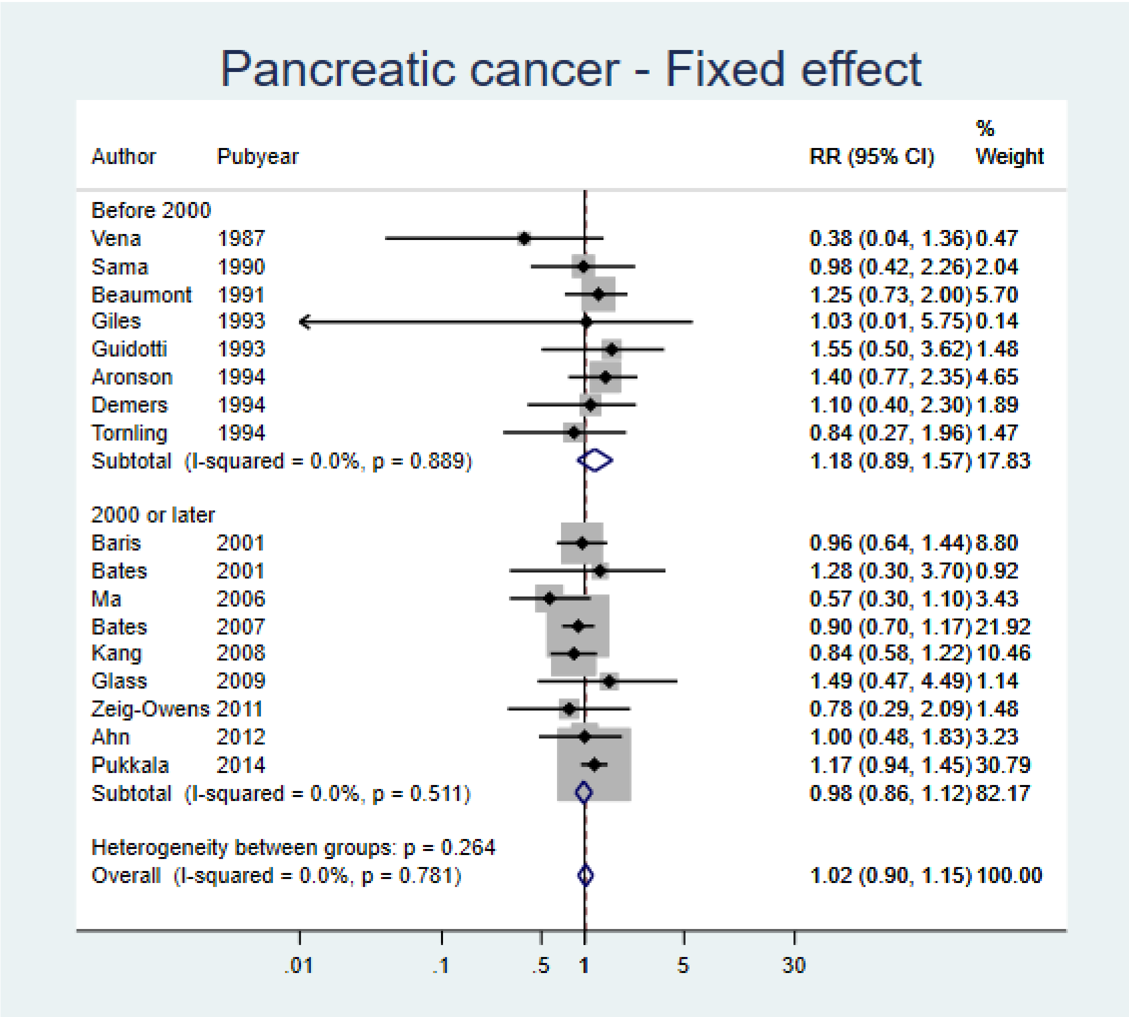

Figure 5 Forest plot for Pancreatic Cancer papers published pre 2000 and post 2000[2]

3.2.6 Laryngeal Cancer

In relation to laryngeal cancer, the previous review did not identify a positive association between occupation as a firefighter and cancer of the larynx (Graveling and Crawford 2010). Since that review, one cohort study has examined this cancer with a similar non-significant outcome, SIR=1.06, 95% CI 0.72-1.50 (Pukkala *et al.*, 2014). A retrospective cohort study by Glass (2009) identified an SIR=0.63, 95% CI 0.31-1.25 for cancer of the larynx, trachea, bronchus and lung,

[2] Minor discrepancies in numbers between the plot and the report are due to rounding

although this group is likely to be dominated by lung cancer. In the case control study by Tsai *et al.*, a similar OR of 0.59, 95% CI 0.39-0.89 was found for firefighters compared to the proportion of control cancer cases (cancers unlikely to be associated with firefighting) who were firefighters.

The 2010 review included publications from Aronson et al 1994, Baris *et al.*, 2001, Beaumont *et al.*, 1991, Demers *et al.*, 1994, Firth *et al.*, 1996, Kang *et al.*, 2008b, Ma *et al.*, 2006, Pukkala et al 2014.

A meta-analysis was prepared from this data and the more recent material. From this, a meta-RR=0.93 95% CI 0.76-1.13 (p=0.007 for heterogeneity) was calculated with a random effects meta-RR=1.00, 95% CI 0.67-1.49; neither of which showed a positive association.

When comparing publications pre and post 2000, a meta-RR=1.57, 95% CI 0.37-6.70 was calculated for studies published before 2000 and a meta-RR=0.86, 95% CI 0.69-1.06 for studies published post 2000; neither of these were statistically significant. The data are presented in Figure 6.

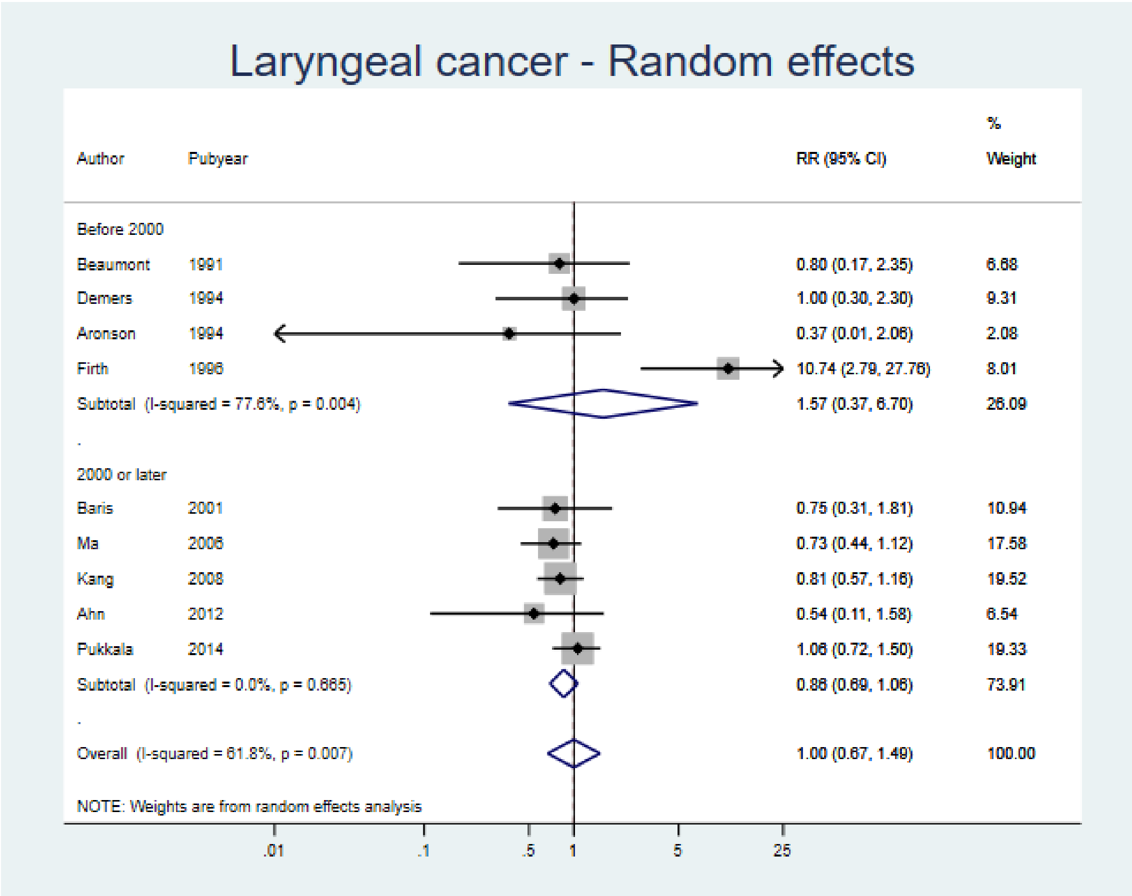

Figure 6 Forest plot for Laryngeal Cancer papers published pre 2000 and post 2000

3.2.7 Lung Cancer

In the original review by Graveling and Crawford (2010), nineteen studies were examined and an estimated risk relative to the general population did not show excess risk for lung cancer among firefighters. Among the more recent publications only one cohort study identified a significant association with an SIR=1.12, 95% CI 1.04-1.21 (Daniels *et al.,* 2013). Ide, (2014) when analysing data from a Scottish firefighter population found that the incidence (6.8 per 100,000) among firefighters was significantly lower than the incident rate within the reference sample (17.1 per 100,000; $p<0.001$), though this may be due to age differences between the groups.

From the other cohort studies included, Glass, (2009) grouped larynx, tracheal, bronchus and lung cancer in Australian firefighters and identified an SIR=0.63, 95% CI 0.31-1.25. Ahn and Jeong, (2015), calculated an SMR=0.58, 95% CI 0.38-0.84 in Korean firefighters for bronchus and lung cancers. Pukkala *et al.,* (2014), calculated an SIR=0.97, 95% CI 0.87-1.09. Zeig-Owens *et al.,* (2011), in their study of firefighters who had attended the World Trade Center collapse, identified an SIR=0.28, 95% CI 0.13-0.62 for firefighters exposed to WTC dust and an SIR=0.52, 95% CI 0.26-1.05 for firefighters not exposed to WTC dust.

One case-control study also examined lung cancer, Tsai *et al.,* (2015) calculated odds ratios for lung and bronchus cancer with a resulting OR=1.08, 95% CI 0.92-1.28 for firefighters compared to the proportion of control cancer cases (cancers unlikely to be associated with firefighting). who were firefighters.

These data provide no evidence of an association between lung cancer and occupation as a firefighter. A further meta-analysis was carried out to examine this in more detail including using data from the current papers cited as well as those from the 2010 review Ahn & Jeong 2015, Aronson *et al.,* 1994, Baris *et al.,* 2001, Bates *et al.,* 2001, Bates, 2007, Beaumont *et al.,* 1991, Burnett *et al.,* 1994, Daniels et al 2013, Demers *et al.,* 1994, Deschamps et al, 1995, Donnan, 1996, Eliopulos et al 1984, Giles *et al.,* 1993, Glass et al 2009, Grimes et al 1991, Guidotti 1993, Kang *et al.,* 2008b, Ma *et al.,* 2006, Pukkala et al 2014, Sama *et al.,* 1990, Tornling *et al.,* 1994, Vena & Fiedler 1987, Zeig-Owens et al 2011.

In the meta-analysis for lung cancer a fixed effect meta-RR=1.00, 95% CI 0.96-1.04 ($p<0.001$ for heterogeneity) was calculated with a random effects meta-RR=0.92, 95% CI 0.84-1.02 identified; neither of which were statistically significant.

To examine trends in time, publications pre and post 2000 were compared and for papers published before 2000, a random effects meta-RR=0.94, 95% CI 0.80-1.12 was found and for publications post 2000, a meta-RR=0.90, 95% CI 0.79-1.03 was identified. The analysis is presented in Figure 7.

While associations between lung cancer and firefighting were not found to be significantly positive, the paper by Pukkala et al (2014) in the Nordic Firefighters study identified that there was a significant association between the Scandinavian firefighters included in the research and lung adenocarcinoma (SIR=1.29, 95% CI 1.02-1.60). Investigating this further, the positive association was found only in Danish firefighters (SIR=1.90, 95% CI 1.09-3.80). The whole Nordic cohort was analysed and an association was found between age at follow-up at being over 70 years old (SIR=1.90, 95% CI 1.34-2.62). These results have not been identified elsewhere and this may be due to lung cancer data not being broken down into different types of lung cancer.

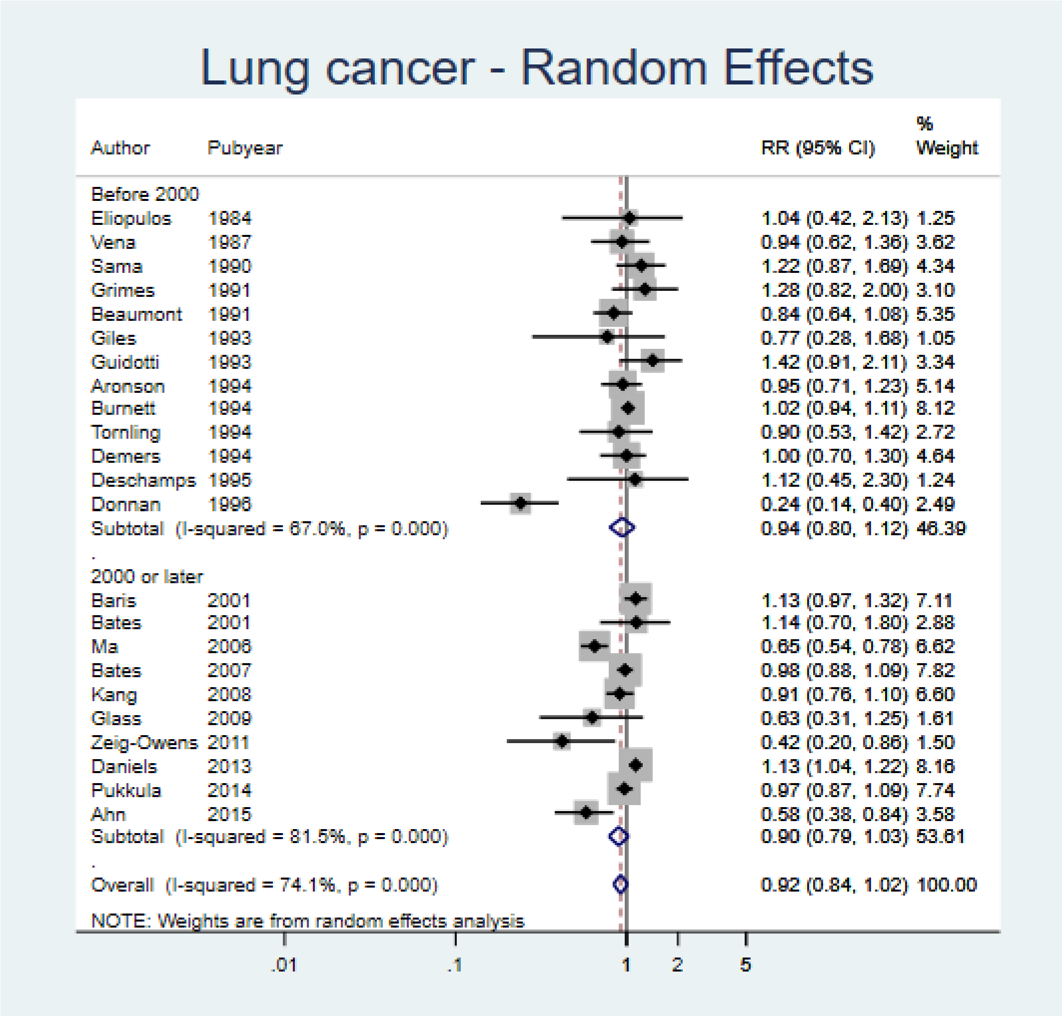

Figure 7 Forest plot for Lung Cancer papers published pre 2000 and post 2000

3.2.8 Melanoma

The incidence of skin cancer was evaluated in the review by Graveling and Crawford (2010) where seventeen papers were selected and a risk relative to the general population was estimated. The review suggested that there was a positive association between skin cancer and firefighting with an estimated risk of between 1.3 and 1.4. However, the review also identified that there were problems with how skin cancer was reported and whether it was a combination of two ICD codes rather than melanoma alone.

Since this review Ide, (2014), found that the incidence rate of melanoma was significantly higher in a Scottish cohort of firefighters (13.6 per 100,000 v 8.1 per 100,000 in the Scottish population ($p<0.001$)) though this may be due, at least in part, to differences in age distribution between the groups. Among Nordic firefighters, an SIR=1.25, 95% CI 1.03-1.51 was calculated (Pukkala *et al.*, 2014). Glass, (2009), examined skin melanoma in Australian firefighters and calculated an SIR=1.33, 95% CI 0.94-1.88. Although not statistically significant, the increased risk ratio is consistent with other work. The one case-control study that examined skin melanoma identified an odds ratio of

OR=1.75, 95% CI 1.44-2.13 in Californian firefighters compared to the proportion of control cancer cases (cancers unlikely to be associated with firefighting) who were firefighters (Tsai *et al.*, 2015).

Data were collated from publications included in the current and previous reviews and a meta-analysis of the data completed. This resulted in a melanoma fixed effects meta-RR=1.39, 95% CI 1.27-1.52 (p=0.068 for heterogeneity). The second analysis examined papers published pre-2000 versus those published post 2000 and these data are presented in Figure 8. For studies published before 2000 the fixed effect RR = 1.78 (95% CI: 1.22 to 2.59) and for studies published in 2000 or later the fixed effect RR = 1.37 (2.24 to 1.50). Thus there is a significant excess of melanoma in the firefighters literature.

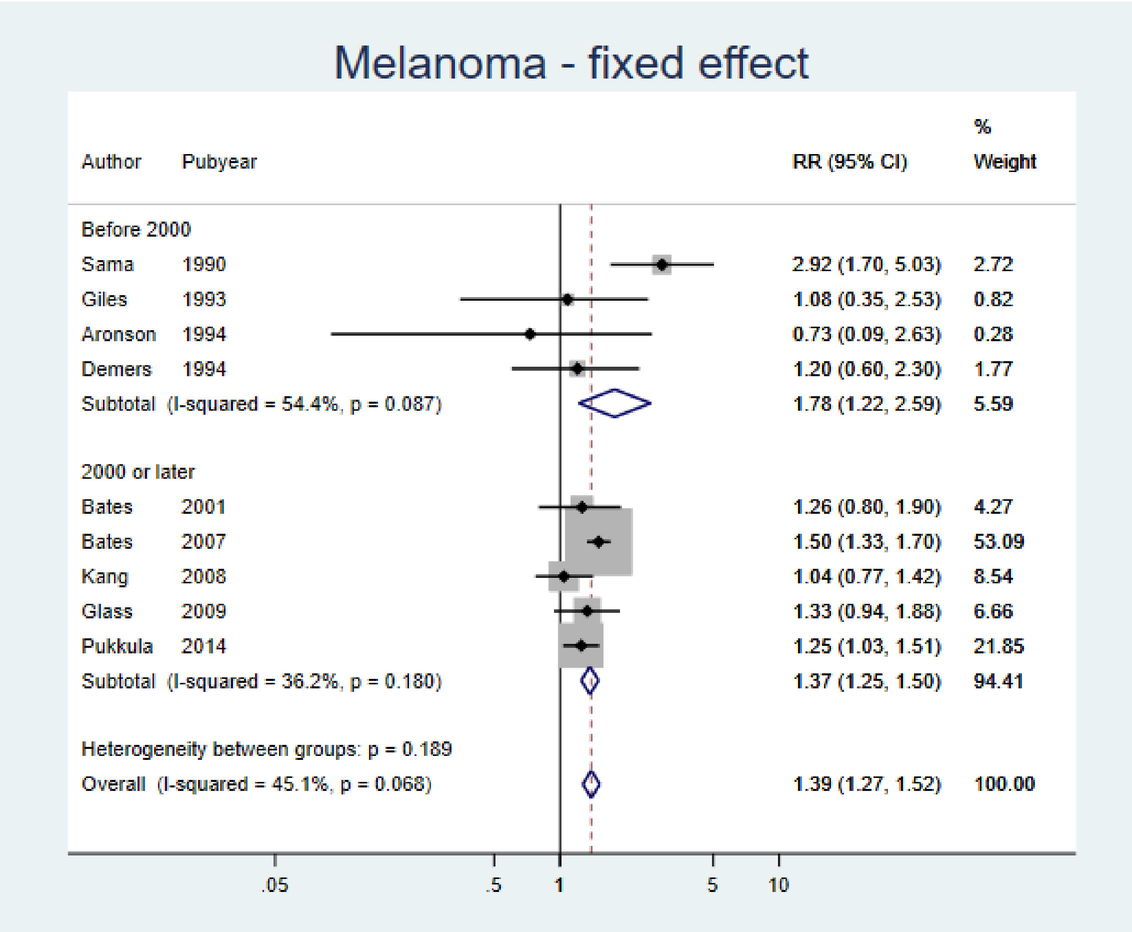

Figure 8 Forest plot for Skin Cancer papers published pre 2000 and post 2000

3.2.9 Prostate Cancer

The review by Graveling and Crawford (2010) examined seventeen papers and an estimated risk relative to the general population was judged to be in the range 1.2-1.3. In reviewing papers published since this review, five cohort studies identified the following. Daniels *et al.*, (2013) identified an SIR=1.03, 95% CI 0.97-1.09 in US firefighters. Glass, (2009) calculated an SIR=0.92, 95% CI 0.61-1.40 in full-time Australian firefighters and Ahn *et al.*, (2012) calculated an SMR=1.32, 95% CI 0.60-2.51 in Korean firefighters. Pukkula *et al.*, (2014) calculated an SIR=1.13, 95% CI 1.05 to

1.22. Zeig-Owens *et al.,* (2011) in the cohort of World Trade Center cancers identified an adjusted SIR=1.21, 95% CI 0.96-1.52 in firefighters exposed to WTC dust and 1.35, 95% CI 1.01-1.81 in non-exposed firefighters. The final cohort study in Nordic firefighters identified an SIR=1.13, 95% CI 1.05-1.22 (Pukkala *et al.,* 2014).

From the one case-control study, Tsai *et al.,* (2015), identified a higher than expected level of prostate cancer (OR=1.45, 95% CI 1.25-1.69) in firefighters compared to the proportion of control cancer cases (cancers unlikely to be associated with firefighting) who were firefighters. No further papers included prostate cancer in their analysis but there does appear to be an association between prostate cancer and occupation as a firefighter.

Further analysis of these data and the data from the 2010 review was carried out including Ahn et al 2012, Aronson *et al.,* 1994, Baris *et al.,* 2001, Bates *et al.,* 2001, Bates, 2007, Beaumont et al 2001, Daniels et al 2013, Demers *et al.,* 1994, Donnan, 1996, Giles *et al.,* 1993, Glass et al 2009, Grimes *et al.,* 1991, Guidotti 1993, Kang *et al.,* 2008b, Ma *et al.,* 2006, Pukkala et al 2014, Tornling *et al.,* 1994, Vena and Fiedler, 1987 and Zeig-Owens et al 2011.

For prostate cancer a fixed effect meta-RR=1.12, 95% CI 1.07-1.15 ($p<0.001$ for heterogeneity) was calculated. The random effects model calculated a meta-RR=1.15, 95% CI 1.05-1.26. Further analysis examining data pre and post 2000 publications identified a meta-RR=1.12, 95% CI 0.78-1.62 pre 2000 versus meta=RR=1.12, 95% CI 1.04-1.21 post 2000. These results suggest an association and the data are presented in Figure 9.

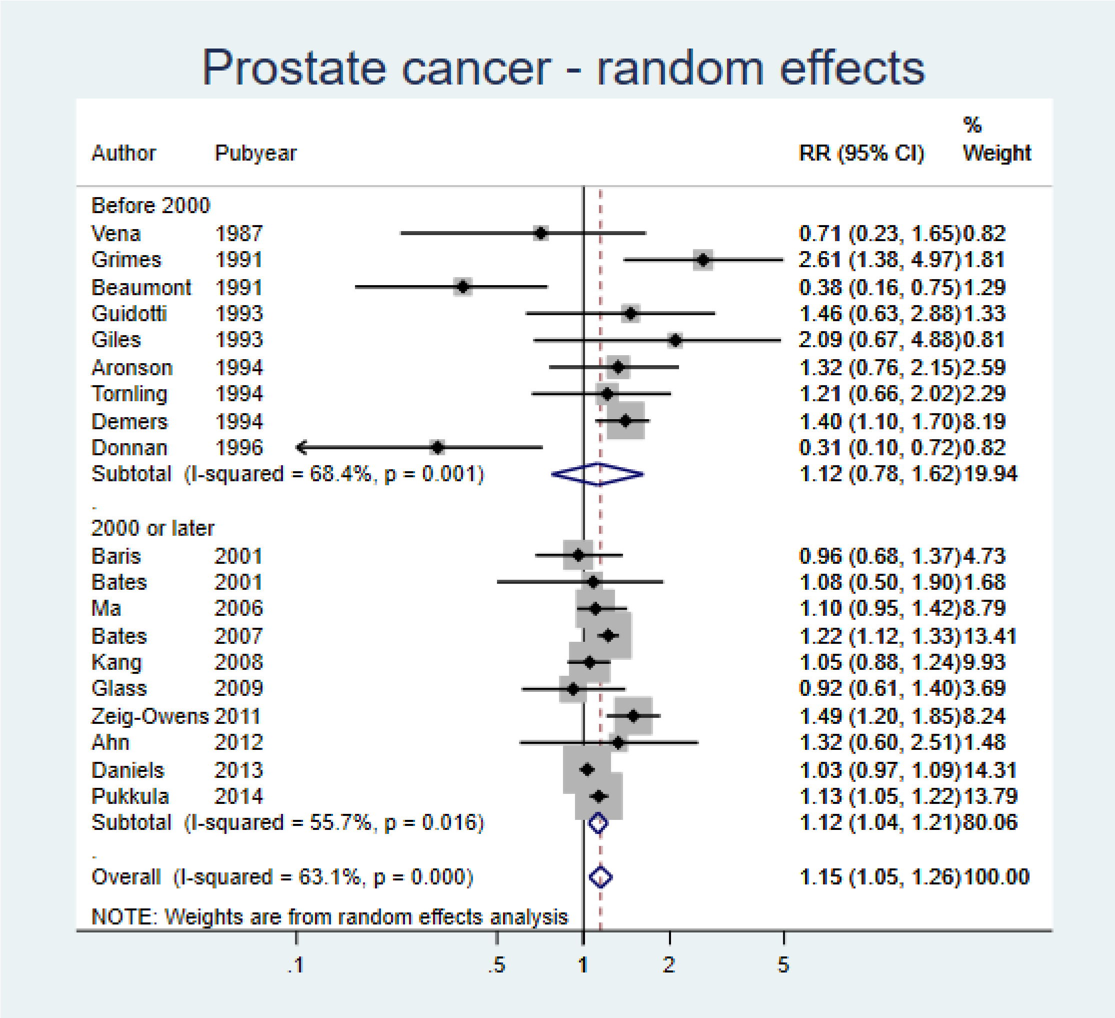

Figure 9 Forest plot for Prostate Cancer papers published pre 2000 and post 2000[3]

3.2.10 Testicular Cancer

Two reviews before 2010 examined testicular cancer in firefighters. The review by Straif *et al.*, (2007) suggested a relative risk of 1.5 for men employed as firefighters. This number was based on the work of Lemasters *et al.*, (2006) SIR=2.50, 95% CI 0.50–7.30 The review by Graveling and Crawford (2010) identified an estimated risk relative to the general population between 1.5 and 8.2 was, but concluded that 1.5 was more likely as the 8.2 was based on one study that has not been corroborated by other publications.

Since 2010, further publications have examined testicular cancer among firefighters. Ide, (2014) when analysing a Scottish cohort of firefighters did not find a significant difference between incidence rates in firefighters (9.1 per 100,000) when compared to the Scottish population (7.7 per 100,000), though this may be due, at least in part, to differences in age distribution between the groups. Four cohort studies also examined testicular cancer among firefighters and identified no

[3] Minor discrepancies in numbers between the plot and the report are due to rounding

significant excess incidence. These comprised Daniels *et al.*, (2013) (SIR=0.79, 95% CI 0.44-1.30), Pukkala *et al.*, (2014) (SIR=0.51, 95% CI 0.23-0.98), Glass, (2009) who found too few cases to calculate an SIR and Zeig-Owens *et al.*, (2011), (SIR=0.86, 95% CI 0.36-2.06 among firefighters exposed to WTC dust and SIR=1.54, 95%CI 0.85-2.78 among non-exposed firefighters). The included case-control study also showed a similar trend with an odds ratio of OR=1.10, 95% CI 0.73-1.66 (Tsai *et al.*, 2015) for firefighters compared to the proportion of control cancer cases (cancers unlikely to be associated with firefighting) who were firefighters.

These data appear to show a reduction in the relative risks of testicular cancer since 2010. A meta-analysis was carried out including data from included papers in the 2010 review (Aronson *et al.*, 1994, Bates *et al.*, 2001, Bates, 2007, Giles *et al.*, 1993, Kang *et al.*, 2008b, Ma *et al.*, 2006, Stang *et al.*, 2003) as well as papers published since (Ahn et al 2012, Daniels et al 2013, Pukkala et al 2014, Zeig-Owens et al 2011).

Based on these papers, a fixed effect meta-RR=1.36, 95% CI 1.16-1.58 (p=0.038 for heterogeneity) was calculated and a random effects meta-RR=1.23, 95% CI 0.95-1.59. In comparing studies published before 2000, a random effects meta-RR=1.89, 95% CI 0.66-5.41 was found pre 2000 and post 2000, a meta-RR=1.19, 95% CI 0.90-1.57 was calculated.

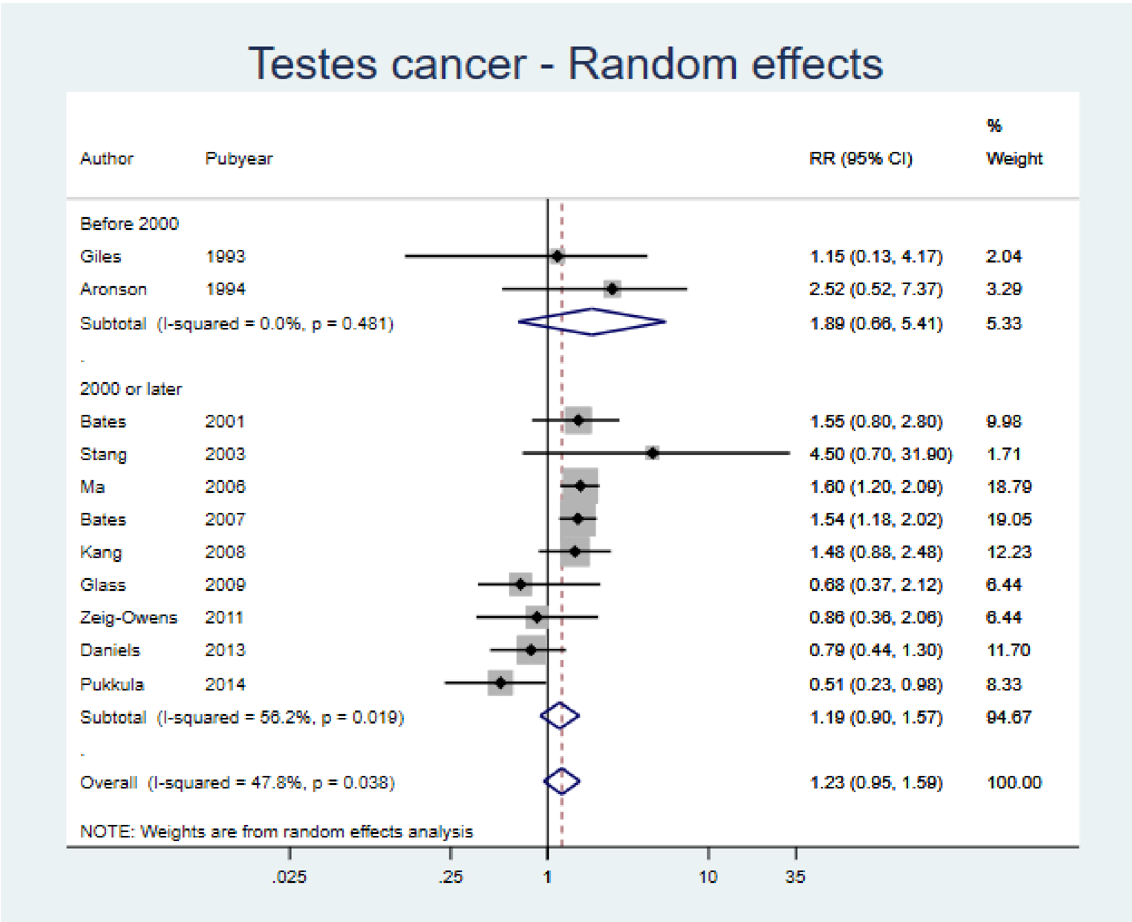

Figure 10 Forest plot for Testicular Cancer papers published pre 2000 and post 2000

3.2.11 Bladder

Graveling and Crawford (2010) examined sixteen papers in relation to bladder cancer and judged the estimated risk relative to the general population to be 1.25. In examining more recent papers, varied results were obtained with differing levels of significance. Among Scottish firefighters, no significant differences were found between firefighters (4.8 per 100,000) and the reference group (5 per 100,000) (Ide, 2014), though this may be due, at least in part, to differences in age distribution between the groups. Daniels *et al.,* (2013) calculated an SIR=1.18, 95% CI 1.05-1.23 in US firefighters. Glass, (2009) examined bladder cancer and identified an SIR=0.40, 95% CI 0.13-1.12 for individuals who had spent at least 12 months as a full-time firefighter and Pukkala *et al.,* (2014) identified in the Nordic cohort an SIR=1.11, 95% CI 0.96-1.28. The work from the World Trade Center firefighters calculated an SIR=1.01, 95% CI 0.56-1.83 among firefighters exposed to WTC dust and SIR=0.79, 95% CI 0.36-1.76 among unexposed firefighters (Zeig-Owens *et al.,* 2011). However, Ahn *et al.,* (2012), found a significant association between bladder cancer and firefighters in their study of Korean firefighters (SIR=1.60, 95% CI 1.01-2.56).

From the one case-control study included in the review, Tsai *et al.,* (2015) identified an OR=0.99, 95% CI 0.78-1.26 for urinary bladder cancer in Californian firefighters compared to the proportion of control cancer cases (cancers unlikely to be associated with firefighting) who were firefighters.

Further analysis was carried out to examine rates over time and a meta-analysis was prepared using data from the current papers cited as well as those from the 2010 review (Ahn et al 2012, Aronson *et al.,* 1994, Baris *et al.,* 2001, Bates *et al.,* 2001, Bates, 2007, Beaumont et al 1991, Burnett et al 1994, Daniels et al 1993, Demers *et al.,* 1994, Donnan, 1996, Glass et al 2009, Guidotti 1993, Kang *et al.,* 2008b, Ma *et al.,* 2006, Pukkala et al 2014, Sama *et al.,* 1990, Vena and Fiedler, 1987, Zeig-Owens et al 2011).

The meta-analysis identified a fixed effect meta-RR=1.12, 95% CI 1.05-1.20 (p=0.010 for heterogeneity) with a meta-RR for random effects equal to 1.15, 95% CI 1.02-1.30. However, it should be noted that two of the risk estimates are based on SMORs and one on PMRs both of which are prone to bias (Stewart & Hunting 1988).

Comparison was made between studies published pre and post 2000. A random effects meta-RR= 1.27, 95% CI 0.91-1.76 was calculated for studies before 2000 and a meta-RR=1.12, 95% CI 1.00-1.26 for studies post 2000. These studies are presented in Figure 11.

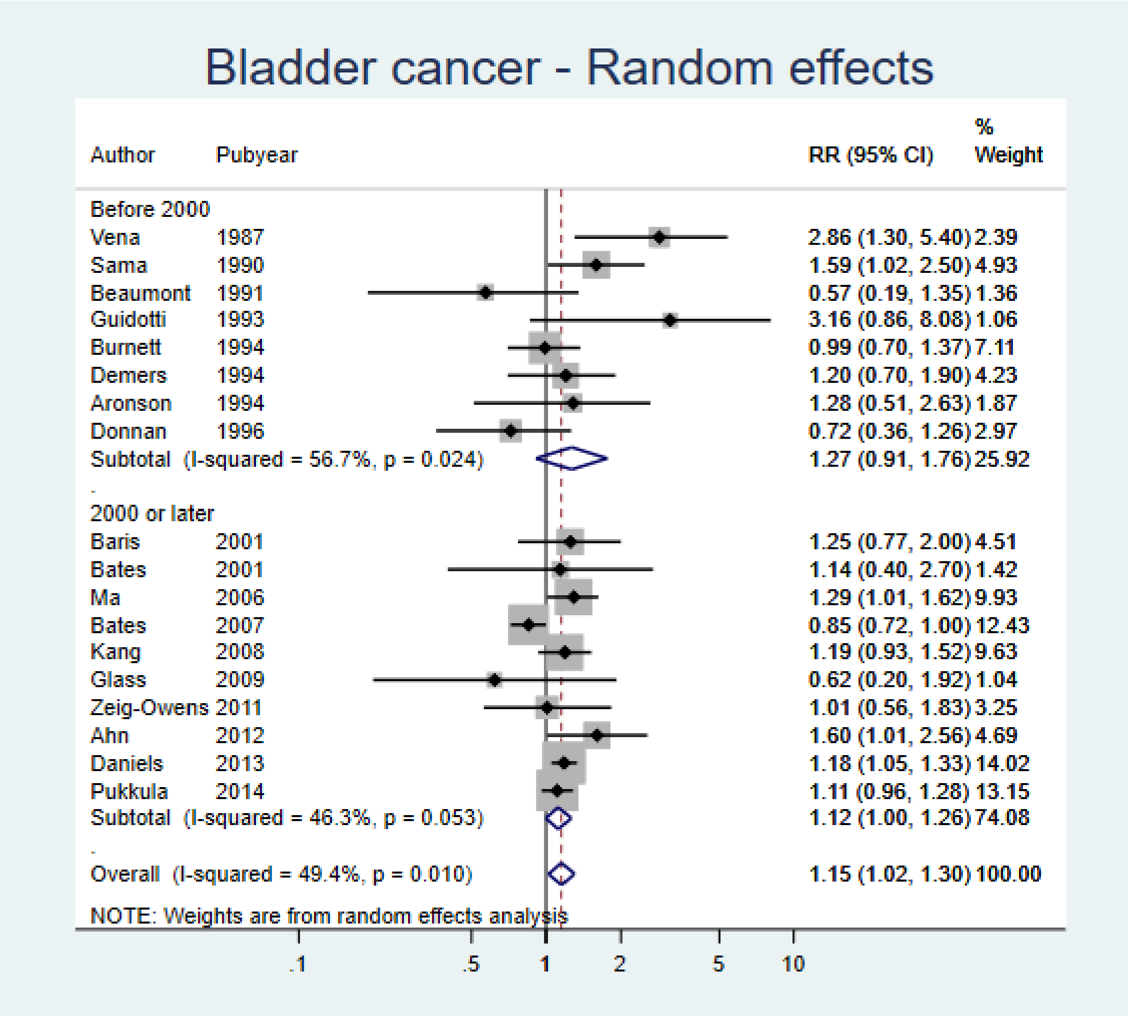

Figure 11 Forest plot for Bladder Cancer papers published pre 2000 and post 2000

3.2.12 Kidney

The association between kidney cancer and occupation as a firefighter was examined by Graveling and Crawford (2010) who estimated a risk relative to the general population of approximately 1.1-1.2, showing a possible excess risk. Since that review, six cohort studies have examined kidney cancer in firefighters including Daniels *et al.*, (2013), who identified a positive and significant association (SIR=1.24, 95% CI 1.04-1.48). Ide, (2014), found a statistically significantly increased incidence rate among Scottish firefighters of 9.1 per 100,000 compared to 4.4 per 100,000 in the population control group (p<0.001), though this may be due, at least in part, to differences in age distribution between the groups. The final four cohort studies included found varied results; however the study by Glass (2009) analysed data including kidney and renal tract (SIR=1.38, 95% CI 0.62–3.07), Pukkula *et al.*, (2014) calculated an SIR= 0.94, 95% CI 0.75- 1.17, Ahn *et al.*, (2012) calculated an SIR=1.6, 95% CI 1.01-2.56 and Zeig-Owens *et al.*, (2011) an SIR=2·91, 95% CI 0·64–13·30.

A meta-analysis was carried out using data from the current papers cited as well as those from the 2010 review (Ahn et al, 2012, Aronson *et al.*, 1994, Baris *et al.*, 2001, Bates, 2007, Beaumont *et al.*, 1991, Burnett *et al.*, 1994, Daniels et al, 2013, Demers *et al.*, 1994, Glass et al, 2009, Guidotti, 1993, Kang *et al.*, 2008a, Ma *et al.*, 2006, Pukkala et al, 2014, Tornling *et al.*, 1994, Vena and Fiedler, 1987, Zeig-Owens et al, 2011). The meta-analysis identified that for fixed effect, the meta-RR=1.12, 95% CI 1.03-1.24 (p=0.014 for heterogeneity). The random effects analysis identified a meta-RR=1.12, 95% CI 0.95-1.31. A further analysis was carried out to examine trends between studies published pre and post 2000. For studies published before 2000, meta-RR=1.28, 95% CI 0.82-2.01 and for studies published post 2000, meta-RR=1.06, 95% CI 0.92-1.23. The forest plot is presented in Figure 12.

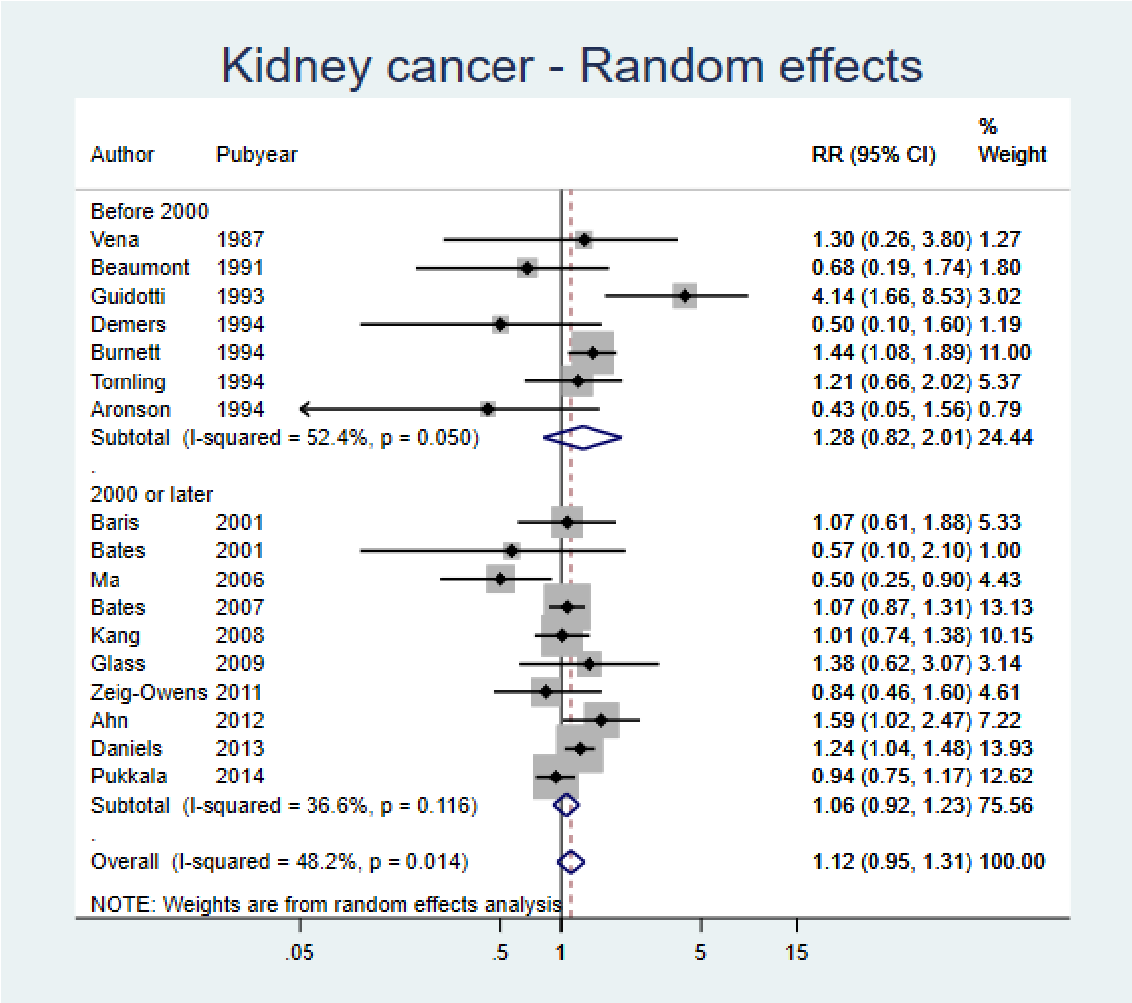

Figure 12 Forest plot for Kidney Cancer papers published pre 2000 and post 2000

3.2.13 Brain

Brain cancer was examined by Graveling and Crawford (2010) and based on an estimated risk relative to the general population estimated from seventeen papers; a relative risk estimate of 1.2 was suggested. From the research published since that date, Ide (2014) did not find a significant difference between Scottish firefighters (4.8 per 100,000) and the comparative general population (5 per 100,000), although there was a difference in age distributions between the groups.

Four cohort studies published since 2010 have examined brain cancer in firefighters, none of which have found a positive association between brain cancer and being a firefighter (Glass, 2009, Ahn *et al.,* 2012, Daniels *et al.,* 2013, Pukkala *et al.,* 2014). Glass 2009 calculated an SIR=1.12, 95% CI 0.47-2.70; Ahn *et al.,* 2012 calculated an SIR=0.44, 95% CI 0.13-1.24; Daniels *et al.,* (2013) with an SIR=1.06, 95% CI 0.78-1.41 and Pukkula *et al.,* (2014) with a calculation of SIR=0.86, 95% CI 0.66-1.10. However, the case-control study (Tsai *et al.,* 2015), did identify a significant association with an OR=1.54, 95% CI 1.19-2.00 for firefighters compared to the proportion of control cancer cases (cancers unlikely to be associated with firefighting) who were firefighters.

A meta-analysis was carried out on the studies reported above and the studies included in the previous review (Aronson *et al.,* 1994, Baris *et al.,* 2001, Bates *et al.,* 2001, Bates, 2007, Beaumont *et al.,* 1991, Burnett *et al.,* 1994, Demers *et al.,* 1994, Grimes *et al.,* 1991, Guidotti, 1993, Kang *et al.,* 2008b, Ma *et al.,* 2006, Sama *et al.,* 1990, Tornling *et al.,* 1994, Vena & Fiedler 1987).

The fixed-effects meta-RR was 1.11, 95% CI 0.99-1.24 (P=0.009 for heterogeneity) and the random effects meta-RR=1.13, 95% CI 0.93-1.37. A further analysis based on publication date (pre and post 2000) calculated a random effects meta-RR=1.49, 95% CI 1.05-2.12 for studies pre 2000 and meta-RR=0.98, 95% CI 0.78-1.22 for studies published post 2000. These data are presented in Figure 13 and suggest that earlier studies did show a significant association but this is less apparent in the more recent papers,

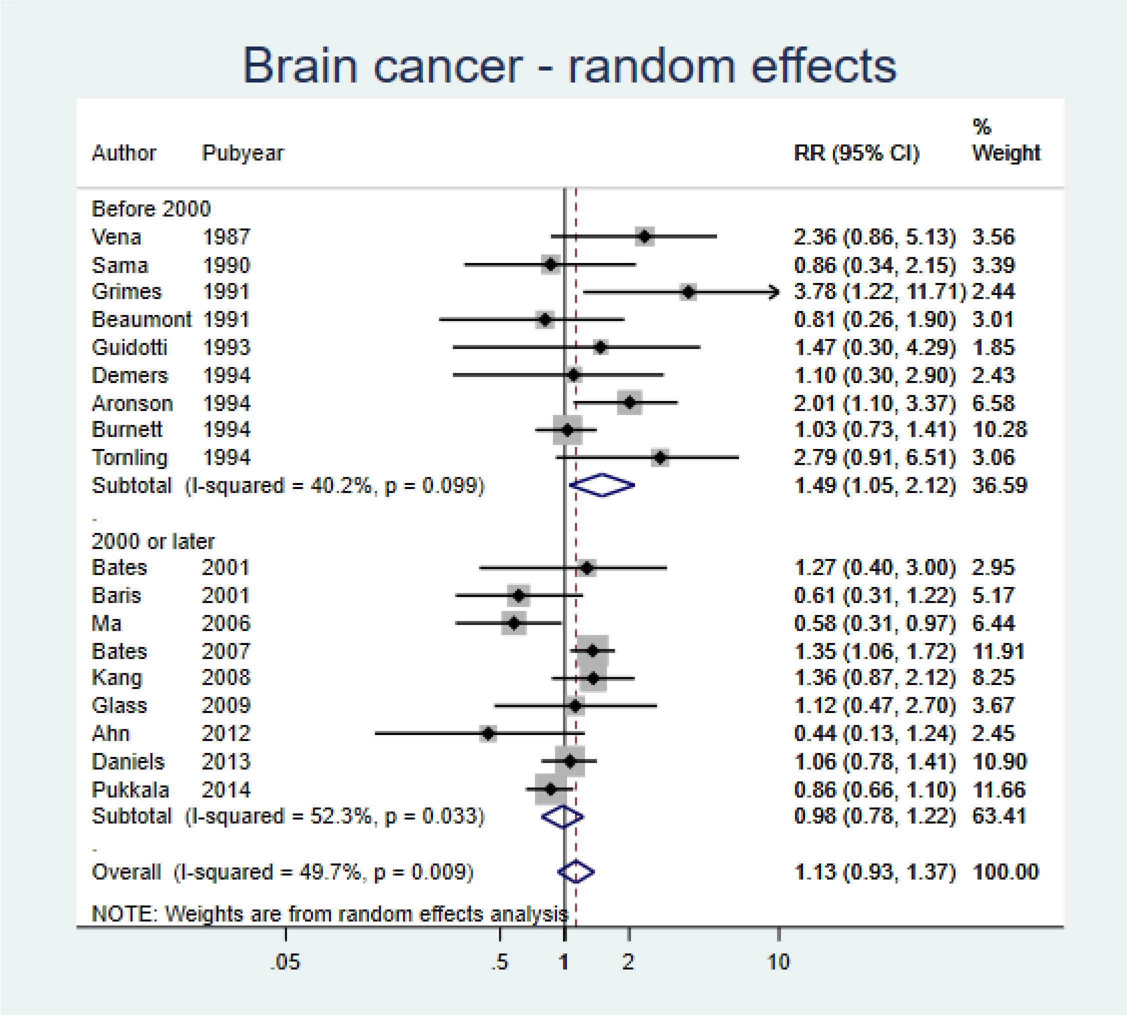

Figure 13 Forest plot for Brain Cancer papers published pre 2000 and post 2000

3.2.14 Thyroid

The systematic review by Graveling and Crawford (2010) did not find any consistent evidence in relation to firefighting and thyroid cancer. In more recent studies, the evidence does not show a statistically significant association (except for firefighters exposed to WTC dust) from three cohort studies including Pukkala *et al.*, (2014) (SIR=1.28, 95% CI 0.75-2.05), Zeig-Owens *et al.*, (2011) (SIR=2.17, 95% CI 1.23-3.82 corrected for surveillance bias among firefighters exposed to WTC dust and SIR=0.59, 95% CI 0.15,2.36 among unexposed firefighters) and Ahn *et al.*, (2012) (SIR=1.00, 95% CI 0.60-1.56). The case-control study by Tsai *et al.*, found similar results (OR=1.27, 95% CI 0.88-1.84) for firefighters compared to the proportion of control cancer cases (cancers unlikely to be associated with firefighting) who were firefighters. These data do not suggest an association between thyroid cancer and firefighting as an occupation.

3.2.15 Lymphatic and Haematopoietic Cancers

The review by Graveling and Crawford (2010) did not find any consistent results in relation to lymphatic and haematopoietic cancers. Analysis of lymphatic and haematopoietic cancers as part of a cohort analysis reported an SIR=1.33, 95% CI 0.91-1.87 (Ahn *et al.*, 2012). In the later paper by Ahn and Jeong (2015), an SMR=0.91, 95% CI 0.51–1.50 was reported.

A meta-analysis was carried out using data from the current and 2010 review (Ahn et al 2015, Aronson et al 1994, Bates et al 2001, Beaumont *et al.*, 1991, Burnett *et al.*, 1994, Demers *et al.*, 1994, Eliopulos *et al.*, 1984, Grimes *et al.*, 1991, Guidotti 1993, Ma et al 2006, Tornling *et al.*, 1994, Vena and Fiedler, 1987). The fixed effect meta-RR=1.05, 95% CI 0.95-1.17 (p=0.001 for heterogeneity). The random effects meta-RR was 0.98 (95% CI: 0.76 to 1.25). When examining data published pre and post 2000, the random effects meta-RR was 1.09, 95% CI 0.88-1.35 for papers published before 2000 and meta-RR=0.83, 95% CI 0.56-1.23 for studies after 2000. These data do not suggest an association between lymphatic and haematopoietic cancer and firefighting.

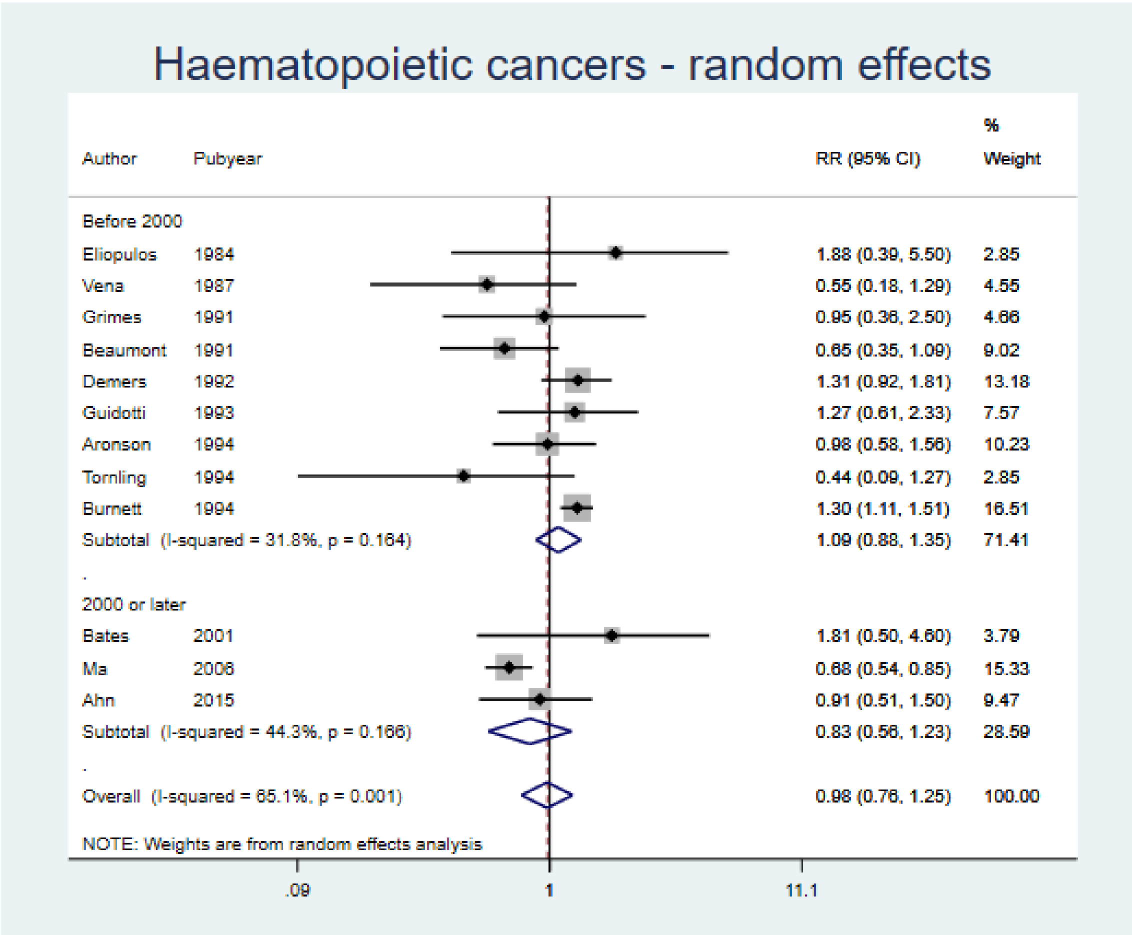

Figure 14 Forest plot for Lymphatic and Haematopoietic Cancer papers published pre 2000 and post 2000

3.2.16 Hodgkin's Disease

Within the previous review, there was too little information on which to base summary risk estimates or to suggest an association between Hodgkin's Disease and firefighting (Graveling and Crawford, 2010). There has been limited research published since then as Zeig-Owens *et al.*, (2011) had too few cases to report on among firefighters exposed to WTC dust, and calculated SIR=0.82, 95% CI 0.20,3.27 among unexposed firefighters. One case-control study based on Californian firefighters identified an odds ratio of 1.15, 95% CI 0.72-1.83 (Tsai *et al.,* 2015) compared to the proportion of control cancer cases (cancers unlikely to be associated with firefighting) who were firefighters. As there were a lack of data to draw on, a meta-analysis was not carried out for Hodgkin's disease.

3.2.17 Non-Hodgkin's Lymphoma (NHL)

Although the systematic review by Graveling and Crawford (2010) estimated a risk relative to the general population ranging from 0.65-2.04 for Non-Hodgkin's Lymphoma (NHL). The review also reports that risk estimates were reducing during the period of papers reviewed (published between 1993 and 2008). In examining more recent research, risk estimates in cohort studies published since 2010 range between 0.98-1.81, for example, Daniels *et al.,* (2013) calculated an SIR=0.99 95% CI 0.83 - 1.16, Glass, (2009) calculated an SIR=0.98, 95% CI 0.49–1.97; Pukkala *et al.,* (2014) with an SIR=1.04 95% CI 0.83 to 1.29, Zeig-Owens *et al.,* (2011) with an SIR=1·81, 95% CI 0·82–3·97 with only one study showing a statistically significant association with firefighting, SIR= 1.81, 95% CI 1.12–2.76 (Ahn *et al.,* 2012). The one case-control study included within this review identified a significant association for Californian firefighters of OR=1.22, 95% CI 1.00-1.50 for firefighters compared to the proportion of control cancer cases (cancers unlikely to be associated with firefighting) who were firefighters. (Tsai *et al.,* 2015)

A meta-analysis was carried out to further evaluate risks of NHL. Data was collated from papers cited above and those included in the previous review (Aronson *et al.,* 1994, Baris *et al.,* 2001, Bates, 2007, Beaumont *et al.,* 1991, Demers *et al.,* 1994, Giles *et al.,* 1993, Kang *et al.,* 2008b, Ma *et al.,* 2006, Sama *et al.,* 1990). The meta-RR calculated for a fixed effects model was meta-RR=1.13, 95% CI 1.04-1.23 (p=0.324 for heterogeneity). When examining the impact of publications pre and post 2000, a meta-RR=1.33, 95% CI 1.08-1.63 for studies published before 2000 and meta-RR=1.10, 95% CI 1.00-1.21 for those published after 2000. These data suggest a decrease in risk when compared to earlier studies but still represent a potentially raised relative risk for this cancer type. Further in-depth analysis is required to evaluate this thoroughly. These data are presented in Figure 15.

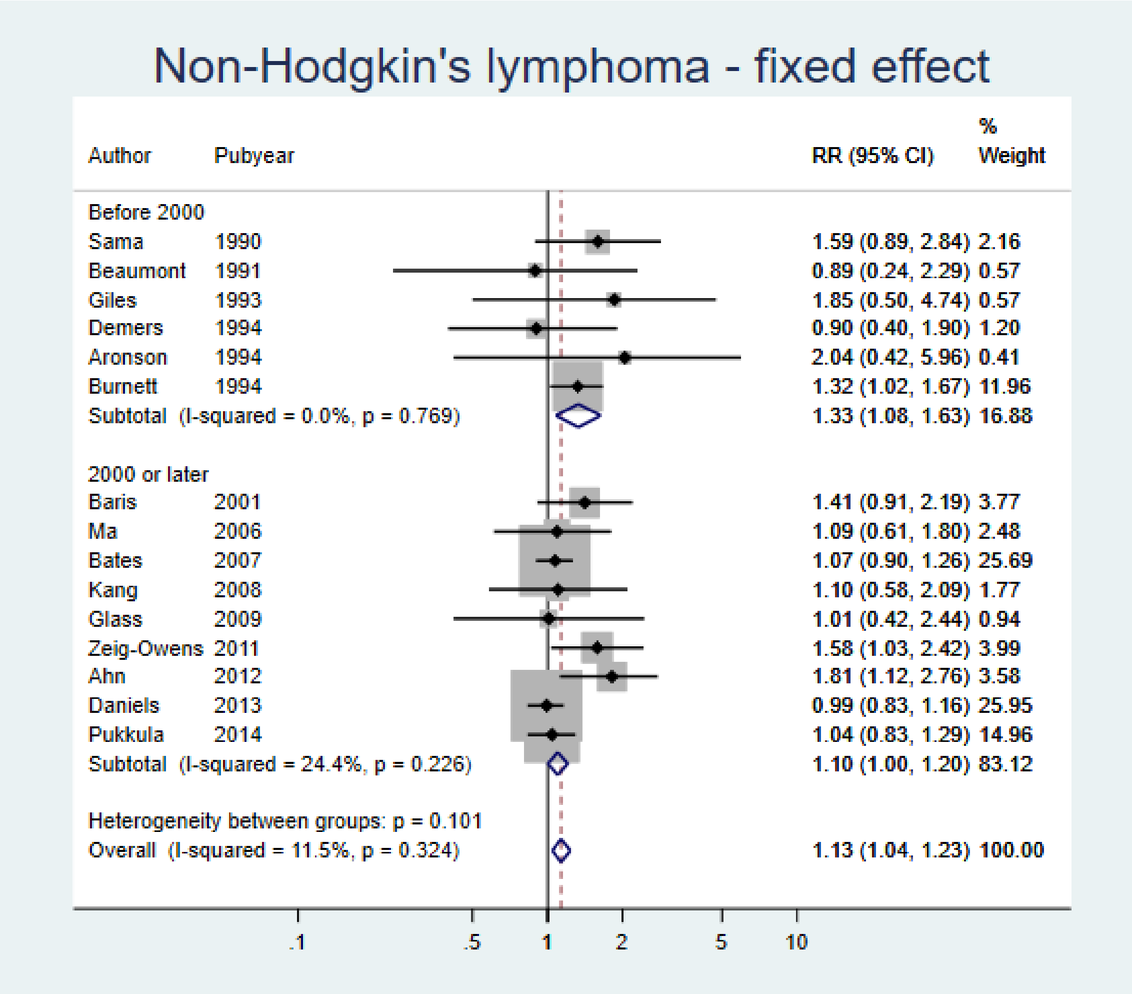

Figure 15 Forest plot for Non-Hodgkin's Lymphoma papers published pre 2000 and post 2000

3.2.18 Multiple Myeloma

In relation to multiple myeloma, an estimated risk relative to the general population was estimated to be between 1.4-1.5 (Graveling and Crawford 2010). Two cohort studies carried out since 2010, while finding risks of between 0.76-1.13, did not reach significance (Daniels *et al.*, 2013 (SIR=0.75, 95% CI 0.52 to 1.06), Pukkala *et al.*, 2014 (SIR=1.13, 95% CI 0.81-1.53). A further two cohort studies including Glass, (2009) did not report a significant excess, while Zeig-Owens *et al.*, (2011) from firefighters exposed to WTC dust identified an SIR=1·49, 95% CI 0·56–3·97. The case-control study of Californian firefighters did reach significance with an OR=1.35, 95% CI 1.00-1.82 (Tsai *et al.*, 2015) compared to the proportion of control cancer cases (cancers unlikely to be associated with firefighting) who were firefighters..

To examine these data further, a meta-analysis was carried out including the studies cited above and those examined in the 2010 review (Aronson *et al.*, 1994, Baris *et al.*, 2001, Bates, 2007, Burnett *et al.*, 1994, Demers *et al.*, 1994, Kang *et al.*, 2008b, Ma *et al.*, 2006).

The fixed effects analysis yielded a meta-SMR=1.08, 95% CI 0.94-1.24 (p=0.233 for heterogeneity). For studies published pre 2000, a random effects meta-RR=1.24, 95% CI 0.97-1.59 was calculated versus a meta-RR=1.01, 95% CI 0.85-1.19 for studies post 2000. These data suggest that there is no significant association between multiple myeloma and work as a firefighter. The data are presented in **Figure 16**Figure 16.

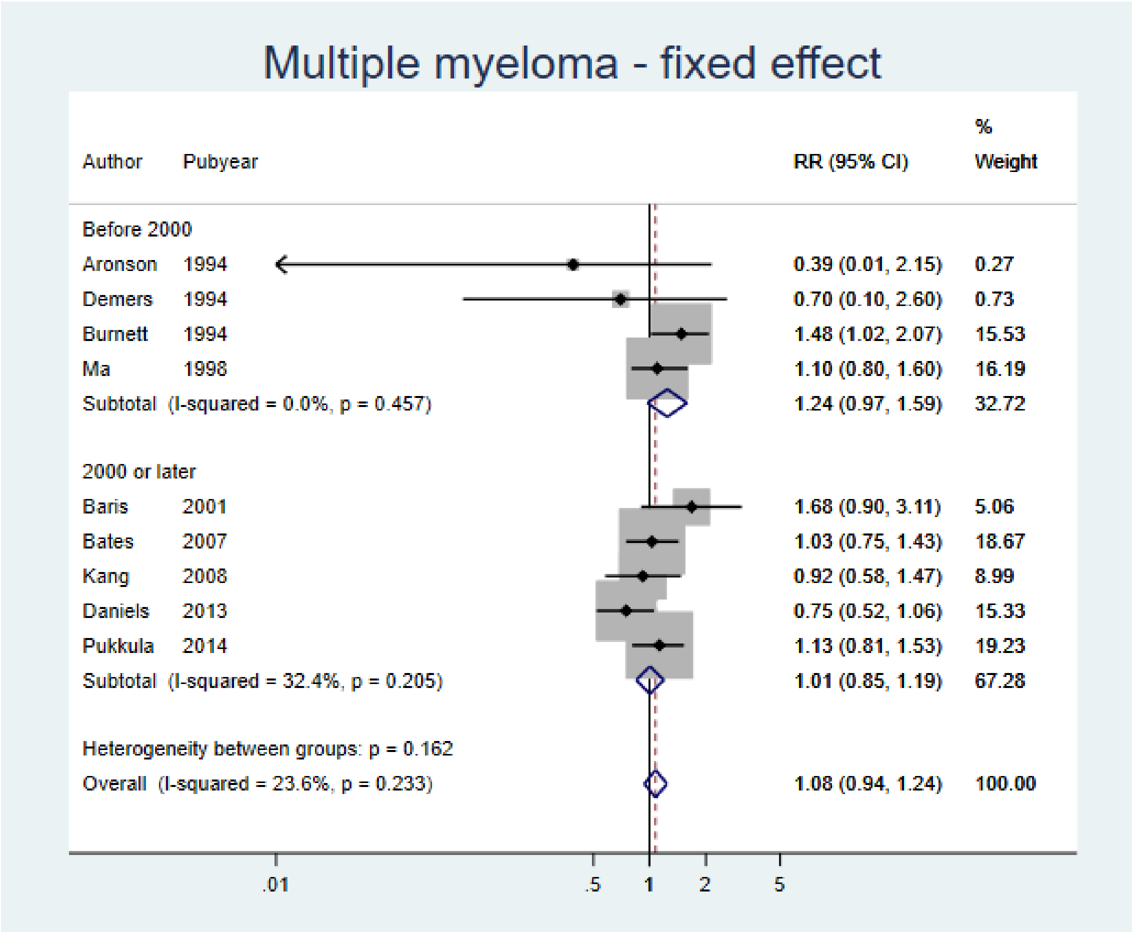

Figure 16 Forest plot for Multiple Myeloma papers published pre 2000 and post 2000

3.2.19 Leukaemia

Research examining leukaemia in firefighters in the 2010 systematic review gave an estimated risk relative to the general population of 1.1 (Graveling and Crawford, 2010). In examining papers since this review, risk estimates in cohort studies have ranged between 0.66-1.2 but none of the studies reach statistical significance (Ahn and Jeong, 2015 (SMR=0.66, 95% CI 0.24–1.44), Daniels *et al.*, 2013 (SIR=0.93, 95% CI 0.74-1.15), Glass, 2009 (SIR=1.20, 95% CI 0.60–2.40), Pukkala *et al.*, 2014 (SIR=0.94, 95% CI 0.71-1.22) and Zeig-Owens *et al.*, 2011 (SIR= 0·98, 95% CI 0·33–2·77)). The one case-control study included in the review did identify a statistically significant association between leukaemia and firefighting in Californian firefighters (OR=1.32, 95% CI 1.05-1.66) compared to the proportion of control cancer cases (cancers unlikely to be associated with firefighting) who were firefighters (Tsai *et al.*, 2015).

The majority of studies do not show an excessive risk of leukaemia in firefighters but a meta-analysis was carried out including the papers cited above and those from the 2010 review Aronson *et al.*, 1994 (2 risk estimates), Baris *et al.*, 2001, Bates *et al.*, 2001, Beaumont *et al.*, 1991, Burnett *et al.*, 1994, Demers *et al.*, 1994, Kang *et al.*, 2008b, Ma *et al.*, 2006, Sama *et al.*, 1990. The meta-analysis for fixed effect identified a meta-RR=1.04, 95% CI 0.94-1.15 (p=0.327 for heterogeneity).

When examining publications published pre 2000, a meta-RR=1.14, 95% CI 0.91-1.42 and for post 2000, meta-RR=1.02, 95% CI 0.91-1.14. Figure 17 presents the Forest Plot of the analysis.

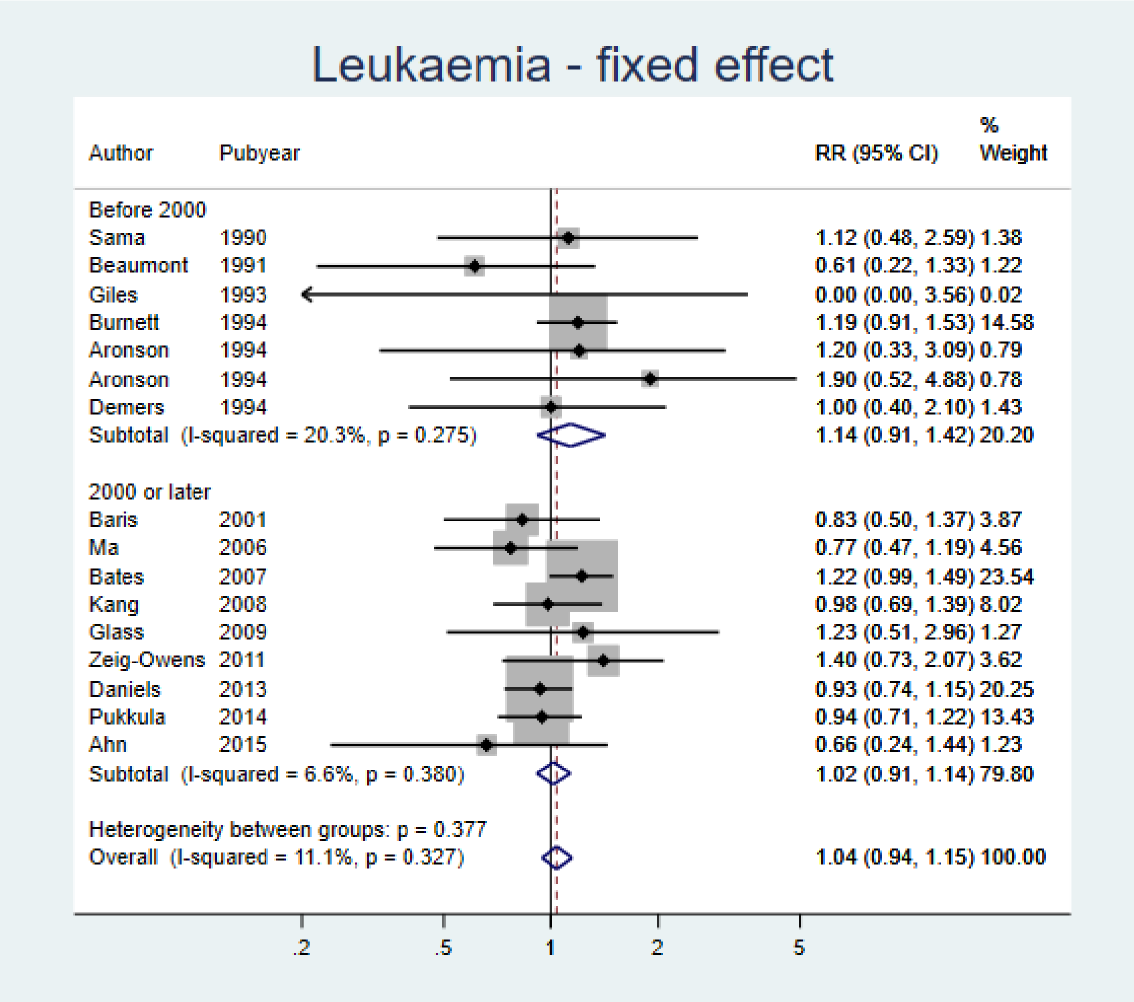

Figure 17 Forest plot for Leukaemia papers published pre 2000 and post 2000

3.2.20 The Meta-Analyses

Data were extracted from individual papers into the meta-analysis and the full results are presented in Table 2 below.

Table 2 Results of Meta-analyses

Cancer	Fixed effect (FE) meta-RR	95% CI for FE meta-RR	P-value for heterogeneity	Random effects (RE) meta-RR	95% CI for RE meta-RR	P-value for publication bias
Stomach	0.99	0.90- 1.09	0.112			0.589
Stomach, before 2000	1.04	0.82-1.32				
Stomach, 2000 or later	0.98	0.88-1.09				
Oesophagus	1.19	1.05 to 1.35	<0.001	1.03	0.76- 1.38	0.835
Oesophagus, before 2000				1.48	0.87 to 2.53	
Oesophagus, 2000 or later				0.95	0.67 to 1.34	
Colorectal, colon & rectum	1.13	1.08-1.19	0.004	1.14	1.05-1.24	0.835
Colon				1.21	1.11-1.31	
Colorectal				0.90	0.70-1.17	
Rectum				1.15	1.04-1.27	
Colon & rectum, before 2000				1.23	1.04-1.45	
Colon & Rectum, 2000 or later				1.11	1.02-1.21	

Cancer	Fixed effect (FE) meta-RR	95% CI for FE meta-RR	P-value for heterogeneity	Random effects (RE) meta-RR	95% CI for RE meta-RR	P-value for publication bias
Pancreas	1.02	0.90-1.15	0.781			0.584
Pancreas, before 2000	1.18	0.89-1.57				
Pancreas, 2000 or later	0.99	0.86-1.12				
Larynx	0.93	0.76-1.13	0.007	1.00	0.67-1.49	0.562
Larynx, before 2000				1.57	0.37-6.70	
Larynx, 2000 or later				0.86	0.69-1.06	
Lung	1.00	0.96-1.04	<0.001	0.92	0.84-1.02	0.829
Lung, before 2000				0.94	0.80-1.12	
Lung, 2000 or later				0.90	0.79-1.03	
Melanoma	1.39	1.27-1.52	0.068			0.609
Melanoma, before 2000	1.78	1.22-2.59				
Melanoma, 2000 or later	1.37	1.25-1.50				
Testes	1.36	1.16-1.58	0.038	1.23	0.95-1.59	0.395
Testes, before 2000				1.89	0.66-5.41	
Testes, 2000 or later				1.19	0.90-1.57	

Cancer	Fixed effect (FE) meta-RR	95% CI for FE meta-RR	P-value for heterogeneity	Random effects (RE) meta-RR	95% CI for RE meta-RR	P-value for publication bias
Lymphatic & Haematopoietic	1.05	0.95-1.17	0.001	0.98	0.76-1.25	
Lymphatic & Haematopoietic, before 2000				1.09	0.88-1.35	
Lymphatic & Haematopoietic, 2000 or later				0.83	0.56-1.23	
Prostate	1.12	1.07-1.15	<0.001	1.15	1.05-1.26	0.953
Prostate, before 2000				1.12	0.78-1.62	
Prostate, 2000 or later				1.12	1.04-1.21	
Bladder	1.12	1.05- 1.20	0.010	1.15	1.02-1.30	0.458
Bladder, before 2000				1.27	0.91-1.76	
Bladder, 2000 or later				1.12	1.00-1.26	
Kidney	1.12	1.03-1.24	0.014	1.12	0.95-1.31	0.954
Kidney, before 2000				1.28	0.82-2.01	
Kidney, 2000 or later				1.06	0.92-1.23	

Cancer	Fixed effect (FE) meta-RR	95% CI for FE meta-RR	P-value for heterogeneity	Random effects (RE) meta-RR	95% CI for RE meta-RR	P-value for publication bias
Brain	1.11	0.99-1.24	0.009	1.13	0.93-1.37	0.080
Brain, before 2000				1.49	1.05-2.12	
Brain, 2000 or later				0.98	0.78-1.22	
NHL	1.13	1.04-1.23	0.324			0.021
NHL, before 2000	1.33	1.08-1.63				
NHL, 2000 or later	1.10	1.00-1.20				
Multiple myeloma	1.08	0.94-1.24	0.233			0.693
Multiple myeloma, before 2000	1.24	0.97-1.59				
Multiple myeloma, 2000 or later	1.01	0.85-1.19				
Leukaemia	1.04	0.94-1.15	0.327			0.209
Leukaemia, before 2000	1.14	0.91-1.42				
Leukaemia, 2000 or later	1.02	0.91-1.14				

3.3 Research papers examining exposure and cancer incidence

One of the major issues when examining firefighters and possible exposures to potential carcinogens are the variety of potential exposures that such individuals are exposed to. Fritschi and Glass (2016) in their commentary on firefighters and cancer identified that exposures are different if the fire is in a rural or urban environment or whether the firefighters are dealing with combustion, chemical spills or substances unknown.

Attempts have been made to measure exposures using techniques such as number of call-outs, years of work and person-hours. As an example, Daniels *et al.,* (2013) examined exposure days, number of fire runs and fire hours. The analysis identified that there were significant associations measured in hazard ratios between the incidence of lung cancer and fire hours (HR=1.39, 95% CI 1.10-1.74) based on 2300 fire hours with a referent of 600 hours, and mortality from leukaemia and the number of fire runs attended (HR=1.45, 95% CI 1.00-2.35) based on 8800 runs with a referent of 2100 runs.

It is important to note here that this is one cohort study, involving US firefighters. Whereas lung cancer rates are not identified as significantly raised internationally, this may be a reflection of different exposures through different methods of working in different countries. This will be a focus of future work.

3.4 Research papers examining other comparable groups and cancer incidence

Other groups of emergency response services were included in the literature search to consider how comparable any increases in risk of cancer between services are. Three papers were identified which studied cancer incidence in police officers.

Finkelstein (1998) analysed cancer incidence data for a cohort of 22,197 police officers in Ontario between 1964 and 1995. The author highlighted that for most cancer sites the SIRs were lower than expected, particularly low for lung cancer, and overall lower than the general population. The only cancer site the SIR was significantly raised was for melanoma 1.45 (90% CI: 1.10-1.88).

Feuer and Rosenman (1986) completed a study on mortality in firefighters and police in New Jersey. They carried out a proportionate mortality ratio (PMR) study of 567 white police officers who died between 1974 and 1980. Compared to the US population, they found significant elevations in cancer rates in white firefighters for skin cancer (PMR=1.48). For comparison with police a significant excess was found for leukaemia (PMR = 2.76).

4 Phase 1: Discussion

4.1 Data used within the report

The data used for the meta-analyses was collated from the published research. As such there are sometimes sources of bias within the data. For example, cohort studies often have uncontrolled confounding and possible selection biases; case-control studies may suffer from recall bias if exposure assessment is subject to participants' recollections. There also exists the possibility of publication bias, especially in the earlier years.

In addition to this, there is also the risk of different diagnostic criteria being used within the paper as well as the collation of different cancers. For example, colon cancer and rectal cancer are often collated together which will have an impact on the analysis. This report separated the data on both cancers, where possible.

The method of data extraction evaluated each of the papers individually but most of the findings were based on 4 cohort studies and one case-control study. While the ICD codes were used to define the cancer endpoint in most of the papers. The data also represent an international perspective and it should be borne in mind that there are different work practices, different levels of protection and different work processes between national borders. For example, in the USA, firefighters often work as paramedics too. At the current time the information is not readily available to evaluate work processes for each individual country.

The majority of the analyses presented use comparisons with the general population. It had been proposed to use other groups such as police officers or paramedics as a comparator but the research identified during the searches was not of a good enough quality to allow an accurate comparison. It was highlighted that for police officers in particular, data on health outcomes are poor at the current time.

4.2 Cancers identified as having a raised risk

From the meta-analyses, a number of cancers were identified as having a raised risk among firefighters including rectal, colon, melanoma, prostate, bladder, and Non-Hodgkin's Lymphoma. One cancer which had previously found to be significantly associated with firefighting by others was testicular cancer but this was not found to be significant in this analysis.

The analysis of melanoma and firefighters' studies also highlighted some of the issues in relation to the diagnostic criteria used, where two or more cancers with potentially different aetiologies are collated together. For the other cancers, where a significant association was identified (prostate, bladder, non-Hodgkin's lymphoma) a further examination of potential risk factors for these cancers should also be examined in the next stage of work. However, the analysis of data for testicular cancer did not affirm the increased risk identified by some earlier analyses. No association was found between lung cancer and firefighting, however one study of Danish firefighters did report a significant association with lung adenocarcinoma.

The absence of a significant association with testicular cancer identified in this work compared to previous studies may be as a result of increased awareness among the firefighting population with regard to screening and self-care which has only become evident in the more recent papers.

4.3 Evidence gaps

There are still a number of evidence gaps within the existing body of research including a lack of research papers including female firefighters and the use of consistent coding of cancers within internationally agreed methods. Furthermore, the research is hindered by a lack of any exposure assessment with regard to the number and length of fire incidents individuals attend during their working life.

While there is an increasing data available for comparison and analysis among firefighters, this also needs to be supported by additional data in relation to exposure-response associations, whether that is to use methods such as fire hours, number of callouts or time in employment. Furthermore, there is a need to allow a sufficient follow-up period for data collection from those who have been involved in firefighting as an occupation.

4.4 Methodological issues

We have only undertaken an exploratory meta-analysis here. In order to explore the robustness of our findings, more detailed analyses are required. Within this analysis, we have included studies with different designs in the same calculations; however, the majority of the studies are cohort studies and so this is unlikely to have had a substantial effect on the findings.

We have carried out many statistical significance tests, greatly increasing the chances of finding randomly raised relative risks where none exists; results that are marginally statistically significant may not be significant.

4.5 Conclusions

The research presented here has identified a number of statistically significant excesses of cancer among firefighters, none of which reached a high level such as a doubling of risk. It is recommended that further research examining the risk factors for colon, rectal, prostate and bladder cancer, and non-Hodgkin's lymphoma be further examined in the next stage of work.

Specific research questions for more detailed examination include:

- Is there any evidence of exposure-response relationships for the six cancer types identified as being associated with occupation as a firefighter where exposure metrics (in the absence of an ability to assess cumulative exposure to individual carcinogens) could include years of employment, time since first employment, number/types of fires attended?
- Occupational cohort studies often have a limited ability to adjust for other confounding factors, and so it would be useful if future analyses were able to assess the importance of these and any other potential sources of bias and confounding.
- Can any specific national factors be identified which could explain the variation in findings in studies from different countries?

5 Phase 1: Acknowledgements

The authors would like to thank the following organisations for funding this research. Kingspan, EUMEPS, EUPC, Plastics Europe, EXIBA, PU Europe.

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Appendix 1. Search Protocol

QUESTIONS TO BE ADDRESSED BY THE RESEARCH

This search protocol was developed in response to the three research questions below. This document only reports on the systematic review and meta-analyses for question 1. In total, 8 of the papers identified within the searches, excluded from question 1 will be included for question 2.

The research questions to be addressed by this review are the following:

1. What is the epidemiological evidence of the incidence of specific cancers in firefighters, and how does this compare to other comparable occupational groups.
2. What is known about the occupational risk factors for those cancers where a higher risk is identified?
3. What occupational hazards are firefighters exposed to?

SEARCH STRATEGY FIRE-FIGHTERS AND CANCER

Q1 What is the epidemiological evidence of the incidence of specific cancers in firefighters, and how does this compare to other comparable occupational groups?

Population
Fire-fighters
Firefighter
Fire Fighter
Firemen
Fire Personnel
Smoke Jumper
Emergency service
Emergency service personnel
Fire Service

Outcomes
Disease
Illness

Ill-health
Occupational disease
Occupational health
Cancer(s)

Study Designs
Systematic reviews
RCTs
Case control studies
Cohort and nested case-control studies
Cross-sectional studies
Observational studies
Narrative Reviews

Inclusion Criteria for Review
Studies containing usable data
In English
Post 2009

Exclusion Criteria for Review
Studies containing no data
Non-English language

Search Tools

Databases
Medline
PsychInfo
Science Citation Indexes

Websites
NIOSH
European Agency for Safety and Health
HSE
CCSRI
Canadian Cancer Society
National Institutes for Health

Organisations
Home Office Fire Research Group
FBU
International Firefighter Organization
International Association of Fire Fighters (IAFF)

Search String

epidemiology AND (incidence OR mortality) AND cancer AND (Fire-fighter OR Firefighter OR "Fire Fighter" OR Firemen OR "Fire Personnel" OR "Smoke Jumper" OR "Emergency service" OR "Emergency service personnel" OR "Fire Service" OR “police officers” OR paramedics)

Cancers
Cancers included in this literature search will be those that have been identified, using epidemiological judgement, as potentially having an increased risk.

Risk factors
Occupational exposure
Life style (smoking, diet, activity, etc)
Genetic factors
Socio-economic factors

Search String
cancer AND “risk factors”

Q3 What occupational hazards are firefighters exposed to?
(not reported in this document)
Population
Fire-fighters
Firefighter
Fire Fighter
Firemen
Fire Personnel
Smoke Jumper
Emergency service
Emergency service personnel
Fire Service

Hazards
Occupational exposure

Search String
(fire-fighter OR Firefighter OR "Fire Fighter" OR Firemen OR "Fire Personnel" OR "Smoke Jumper" OR "Emergency service OR "Fire Service") AND (hazards OR risks) AND (exposure OR epidemiology)

Appendix 2. Papers Excluded During Data Extraction

Authors	Reason for Exclusion
Aschebrook-Kilfoy *et al.*, (2014)	Does not include firefighters in the sample
Beranger *et al.*, (2013)	Does not include firefighters in the sample and considers cancer in offspring.
Amadeo *et al.*, (2015)	General mortality opposed to cancer
Walsh *et al.*, (2014)	Cancer screening not occurrence
Yip *et al.*, (2016)	Does not include cancer outcomes
Zeig-Owens *et al.*, (2016)	Comparison of diagnosed cancer and self-report
Centers for Disease Control and Prevention (2012)	Final ruling on cancer and compensation
Poston *et al.*, (2012)	Tobacco use among firefighters
Wong & Gomes (2016)	Duplicate
Wirth (2013)	Duplicate

Appendix 3. Studies Included in the Review

Author	Type of Study	Population	Findings	Quality Assessment
Ahn & Jeong (2015)	Cohort Study	Firefighters and Emergency Responders	The cohort was comprised of all male professional emergency responders employed for at least one month between January 1980 and December 2007. In total 33,442 male workers were followed for 377,703 person-years. Firefighters made up 81% of the cohort (29, 453 workers). For firefighters SMR for cancer was calculated for stomach cancer (0.63, 95% CI 0.43-0.88), colorectal cancer (0.65, 95% CI 0.34-1.14) for liver cancer (0.55, 95% CI 0.41-0.73) lung cancer (0.58, 95% CI 0.38-0.84) leukaemia (0.66, 95% CI 0.24-1.44) Lymphohematopoietic (0.91, 95% CI 0.51-1.50). Within the emergency responders group (all of the cohort), cancers examined included stomach (0.61, 95% CI 0.43-0.85), colorectal (0.66, 95% CI 0.35-1.14), liver (0.52, 95% CI 0.39-0.69), lung (0.59, 95% CI 0.39-0.85), leukaemia (0.61 95% CI0.22-1.32), lymphohematopoeitic (0.89, 95% CI 0.51-1.45). Mortality due to exposure to smoke, fire, and flames (SMR=3.11, 95% CI=1.87–4.85) was significantly increased among ERs and among firefighters SMR=2.48 (95% CI 1.33-4.17) All-cause mortality (ARR=1.46, 95% CI=1.13–1.89), overall cancer mortality (ARR=1.54, 95% CI=1.02–2.31) and mortality of external injury, poisoning and external causes (ARR=3.13, 95% CI=1.80–5.46) were significantly increased among firefighters employed 20 years compared to those of non-firefighters and firefighters employed < 10 years.	+
Ahn, *et al.*, (2012)	Cohort Study	Korean Firefighters	The total cohort was 33,146 male emergency responders and within the cohort, 29,438 were firefighters. Data were collected between 1980 and 2007. Standard incidence ratios identified that among firefighters risks for	++

Author	Type of Study	Population	Findings	Quality Assessment
			colorectal cancer (SIR=1.27, 95% CI 1.01-1.59), kidney cancer (SIR=1.56, 95% CI 1.01-2.41), bladder cancer (SIR=1.6, 95% CI 1.01-2.56) and non Hodgkin's lymphoma (SIR=1.69, 95% CI 1.01-2.67) were significantly higher than the male Korean population. When examining duration of employment, bladder cancer was at an increased incidence at employment of 10 years and longer compared to less than 10 years' employment (SIR=1.98, 95% CI 1.13-3.22).	
Bonauto and Silverstein (2007)	Review	Firefighters	This was a review of epidemiological studies to examine the strength of association between firefighters and selected cancers with a view to considering a presumption of the cancers for compensation. The review identified that for multiple myeloma, most studies were limited by small numbers. However, the majority did identify increased rates with an increased risk after 20 years' service. For stomach cancer, inconsistent results were found with again the limitation of small numbers in some studies. An association with exposure was identified in one study with increasing risk in those with over 30 years of employment (SIR=2.56, 95% CI 1.49-5.05) and attending over 1000 fires (SIR=2.64, 95% CI 1.36-4.61). The results for prostate cancer in the 15 included studies were again inconsistent. One study did identify increased mortality for those working less than 9 years (SMR=2.36, 95% CI 1.42-3.91) but not for those working >9 years, and another study found increased mortality in those with over 30 years employment (SMR=1.42, 95% CI 1-2) but not among those with <10 or >20 years employment. The review included 4 papers examining testicular cancer where again limitations with regard to numbers were highlighted for some studies. One study did identify an increased	-

Author	Type of Study	Population	Findings	Quality Assessment
			incidence for firefighters with between 11-20 years employment (SIR=3.51, 95% CI 1-9) but not among those with <10 or >20 years employment.. For rectal cancer, 13 studies were included but only one significant association was identified with an increased PMR in those with age of occurrence less than 65 years old (PMR =1.86, 95% CI 1.1-2.94). Digestive tract cancer risks were evaluated using 9 studies but again results were inconclusive and did not show a positive association apart from increased SIR for cases occurring at 65 years of age or over (SIR=3.65, 95% CI 1.13-7.94). Conflicting evidence of any meaningful association between prostate cancer and the firefighting occupation is derived from the studies described above.	
Daniels *et al.*, (2013)	Cohort Study	Firefighters	The study examined mortality patterns and incidence among a group of 29 993 firefighters which measured mortality and incidence rates of specific cancers, compared to the US general population. Analyses focused on 15 outcomes of a priori interest. Sensitivity analyses were conducted to examine the potential for significant bias. Person-years at risk totalled 858 938 and 403 152 for mortality and incidence analyses, respectively. All-cause mortality was at expectation (SMR=0.99, 95% CI 0.97 to 1.01, n=12 028). There was excess cancer mortality (SMR=1.14, 95% CI 1.10 to 1.18, n=3285) and incidence (SIR=1.09, 95% CI 1.06 to 1.12, n=4461) comprised mainly of digestive (SMR=1.26, 95% CI 1.18 to 1.34, n=928; SIR=1.17, 95% CI 1.10 to 1.25, n=930) and respiratory (SMR=1.10, 95% CI 1.04 to 1.17, n=1096; SIR=1.16, 95% CI 1.08 to 1.24, n=813) cancers. This study is the first to report excess malignant mesothelioma	++

Author	Type of Study	Population	Findings	Quality Assessment
			(SMR=2.00, 95% CI 1.03 to 3.49, n=12; SIR=2.29, 95% CI 1.60 to 3.19, n=35) among US firefighters. Mortality for the few women in the cohort did not show an excess and most cancer deaths were from breast cancer and bladder cancer but this was based on a few cases for each cause. Over time, mortality rates from oesophageal cancer among the full cohort were shown to be increased between 10-20 years' service and 20-30 years but not after 30 years. Stomach cancer mortality was increased after 30 years of service. Intestinal cancer mortality rates were increased between 20-30 years of service; lung cancer mortality rates were significantly increased at 20-30 years of service; as were kidney cancer mortality rates. Non-Hodgkin's lymphoma had a significantly higher than expected mortality between 20-30 years' service and after 30 years of service.	
Daniels *et al.*, (2015)	Cohort Study	Firefighters	This research paper examined a cohort of 19309 male firefighters who were eligible for the study where there had been 1333 cancer deaths and 2609 cancer incidences. The aim was to examine exposure–response relationships between surrogates of firefighting exposure and select outcomes among previously studied US career firefighters. Eight cancer and four non-cancer outcomes were examined using conditional logistic regression. Incidence density sampling was used to match each case to 200 controls on attained age. Days accrued in firefighting assignments (exposed-days), run totals (fire runs) and run times (fire-hours) were used as exposure surrogates.	++

Author	Type of Study	Population	Findings	Quality Assessment
			Significant positive associations between fire-hours and lung cancer mortality (Hazard Ratio (75th centile to 25th centile) 1.39, 95% CI 1.12-1.73) and incidence (HR 75:25 1.39, 95% CI 1.1-1.74) were evident. A similar relation between leukaemia mortality and fire-runs was also found (HR 75:25 1.45, 95% CI 1.00-2.35). The lung cancer associations were nearly linear in cumulative exposure, while the association with leukaemia mortality was attenuated at higher exposure levels and greater for recent exposures. Significant negative associations were evident for the exposure surrogates and colorectal and prostate cancers, suggesting a healthy worker survivor effect possibly enhanced by medical screening.	
Davis *et al.*, (2012)	Cohort Study	Criminal Investigators, US with BATFE	This was a cohort study of 3,768 individuals predominately made up of criminal investigators the majority of whom were male. The study examined the incidence of bladder cancer but did include both self-report and clinically diagnosed outcomes. Person-years were also calculated and seven cases of bladder cancer, five medically documented, occurred during the period of study. Standardised incidence ratios were calculated and found to be significant for all cases (SIR=2.41, 95% CI 1.17-4.96) but not significant where only the 5 medical cases were included. For the breakdown of the cohort into white males, white males undertaking medical surveillance (‘exams’) and those with the Job 1811 as their title, significantly increased incidence was found in those with exams (SIR=4.34, 95% CI 1.85-10.16 for the 5 medical cases), those with Job 1811 (SIR=5.45, 95% CI 2.33-12.76 for the 5 medical cases) In these groups incidence was also significantly raised when all 7 cases were included. The paper suggests that some investigators are exposed to post-fire and post-blast scenes	+

Author	Type of Study	Population	Findings	Quality Assessment
			where there is the potential to be exposed to risks for bladder cancer, although this was not studied directly.	
Driscoll *et al.*, (2016)	Cohort Study	Firefighters	The aim of the study was to produce a population based estimate of formaldehyde exposure. The main exposure routes for firefighters were through exposure to particle board during firefighting and overhaul.	+
Fang *et al.*, (2011)	Case-control Study	General Population and firefighters	This was a Canadian population based case-control study which aimed to examine elevated colon cancer risks in occupation. The analysis included 15463 incident cases and a number of organisations. Firefighters were not found to have an elevated risk of colon cancer within this study.	++
Fritschi & Glass (2016)	Consensus or Expert Opinion	Firefighters	This was a commentary with regard to firefighters and cancer and where we are now. The article highlights the different incidence rates in different cohorts and that firefighting includes a range of diverse activities. Exposures may be different due to the types of fires, the sites of fires (urban or rural), chemical spills, MVAs and the materials used in buildings have changes. Firefighters should be encouraged to reduce exposure by PPE and RPE as well as protecting the skin.	+
Glass, (2009)	Cohort Study	Australian Firefighters	This was a retrospective cohort study of firefighters. The analysis identified 208 cancers among the 6964 men and 9 among the 540 women. There were no excess incidences established for any of the cancers examined by the research for men. For women, there were too few cases to report.	++

Author	Type of Study	Population	Findings	Quality Assessment
			In addition, similar patterns of cancer incidence were found when restricting the analysis to those male fire fighters with more than 1 years' service or when restricting the analysis to fulltime fire fighters	
Graveling & Crawford (2010)	Systematic Review	Firefighters and cancer	This was a systematic review published for the UK Industrial Injuries Advisory Council (IIAC) to examine possible prescription of different health risks including cancer in firefighters as an industrial injury. The review examined cancers and identified that while none of the cancers examined reached a doubling of risk (the threshold for prescription in the UK), there was an observed increased risk for (above 1) for mouth cancers, oesophageal, colon cancer, rectal cancer, skin cancer, prostate cancer, testicular cancer, bladder cancer, kidney cancer, brain cancer, lymphatic and haematopoietic cancers, non-Hodgkin's Lymphoma, multiple myeloma and leukaemia.	+
Gomes *et al.*, (2011)	Review	General Population and firefighters	This was a review examining brain neoplasms. The study identified that firefighters had a moderately higher risk for brain neoplasms compared to other workers (SMR = 1.9, 95% CI 1.1-1.7). The review cites other relevant studies but does not synthesise the knowledge.	+
Gu, *et al.*, (2011)	Cohort Study	Police Officers	This is a cohort study of US police officers. In total 2234 white male police officers were included in the study with a follow-up of 31 years. The analysis identified that 406 officers developed cancer and the overall cancer incidence was similar to the general population. (Standardized Incidence Ratio [SIR] = 0.94, 95%, Confidence Interval [CI] = 0.85–1.03).An elevated risk of Hodgkin's lymphoma was observed relative to the general population (SIR = 3.34, 95%, CI= 1.22–7.26). The risk of brain	++

Author	Type of Study	Population	Findings	Quality Assessment
			cancer, although only slightly elevated relative to the general population (SIR = 1.61, 95%, CI = 0.73–3.05), was significantly increased with 30 years or more of service (SIR = 2.92, 95%, CI = 1.07–6.36). Incidence ratios were significantly lower than expected for skin and bladder cancer. Police officers were at increased risk of Hodgkin's lymphoma overall and of brain cancer after 30 years of service.	
Guidotti, (2007)	Review	Firefighters	The paper discusses causality in cancers associated with firefighting and compensation in Canada. The paper suggests that presumption is justified for bladder, kidney, testicular, brain and lung cancer among non-smokers. There were difficulties in making presumption for non-Hodgkin's lymphoma, leukaemia and myeloma but the authors conclude that these also merit an assumption of presumption. .	-
Ide, C. W.	Cohort Study	Firefighters with a general population comparator group	The study aimed to examine cancer morbidity and mortality among Scottish firefighters. The sample ranged between 2173-2308 serving firefighters between 1984 and 2005. Overall mean annual cancer incidence and mortality rates (expressed per 100,000) were lower in the firefighters (86.5 versus 123.7, $P < 0.01$, 95% [CI] −290.3 to −209.7 and 20.4 versus 59.9, $P < 0.001$, 95% CI −57.5 to −22.5, respectively). The incidences of melanoma and kidney cancers were higher (13.6 versus 7.7, $P < 0.001$ 95% CI 3.0 to 8.8 and 9.1 versus 4.4, $P < 0.01$, 95% CI 2.4 to 6.7) as was mortality from kidney cancer (6.5 versus 1.9, $P < 0.01$, 95% CI 2.8 to 6.4). Large bowel (9.1 versus 13.8, $P < 0.01$, 95% CI −7.7 to −1.7) and lung (6.8 versus 20.4, $P < 0.001$, 95% CI −7.7 to -1.0) had a significantly lower than expected incidence. It should be noted	-

Author	Type of Study	Population	Findings	Quality Assessment
			however that there were significant differences in the age distributions of the cases and controls. Mean age and length of service at diagnosis were 43 years (range 28–54) and 19 years (range 2–31), respectively. These results are generally consistent with other studies of firefighters. The most common tumours were generally those associated with young and middle-aged men.	
Paget-Bailly, *et al.,* (2013)	Case-control Study	Firefighters	This paper is from a French population based research project (ICARE) which examined occupation and head and neck cancer. The analysis included 2415 cases and 3555 controls. Within the cancer cases, there were 13 firefighters and 12 firefighters among the controls. For those ever employed as a firefighter, the odds ratio of risk of head or neck cancer was 3.9 (95% CI 1.4-11.2) and for those with more than 10 years as a firefighter at the odds ratio was 7.6 (95% CI 2.4-24). Risk was not elevated for firefighters with less than 10 years in the occupation,	++
Pukkula *et al.,* (2014)	Cohort Study	Firefighters	This is a cohort study of 16,422 firefighters from Sweden, Finland, Norway, Denmark and Iceland identified from linked census and cancer registry data between 1961 and 2005. For all cancers the SIR was 1.06 95% CI 1.02-1.11. For specific cancers significantly increased SIRs were found for adenocarcinoma of the lung (1.24 95% CI 1.02-1.6) for skin melanoma (1.25, 95% CI 1.03-1.51), and prostate cancer (1.13, 95% CI 1.05-1.22). The study also examined cancer incidence in different age groups, 30-49 years, 50-69 years and 70+ years. These data identified an increase in SIR with for adenocarcinoma (ages 70+ SIR 1.90, 95% CI 1.34-2.62) but not for skin melanoma or prostate cancer, which were significantly increased only in	++

Author	Type of Study	Population	Findings	Quality Assessment
			the youngest age group. In addition, an increased risk, mainly in ages of 70 years and higher, was observed for non-melanoma skin cancer (SIR=1.40, 95% CI 1.10 to 1.76), multiple myeloma (SIR=1.69, 95% CI 1.08 to 2.51), and mesothelioma (SIR=2.59, 95% CI 1.24 to 4.77). In contrast to earlier studies, the incidence of testicular cancer was decreased (SIR=0.51, 95% CI 0.23 to 0.98). Some of these associations have been observed previously, and potential exposure to polycyclic aromatic hydrocarbons, asbestos and shift work involving disruption of circadian rhythms may partly explain these results.	
Samet & Bhavsar (2005)	Review	Firefighters	This is a report that covers a number of different aspects cancer in firefighters in Maryland. This report provides the findings of a ten-month study of a possible cancer cluster among fire fighters in Anne Arundel County. Firefighters are exposed to smoke generated by the combustion of diverse materials, and the smoke is known to contain carcinogens. This report covers a range of topics and activities relevant to interpreting the possible cancer cluster. These activities included characterizing the cluster and evaluating potential exposures to PCBs and their combustion by-products of fire fighters who participated in training fires at the Academy, assessment of applicable scientific literature, and consideration of research that might provide greater insight into the risks sustained by fire fighters. The authors suggest that the risk of death from brain cancer was increased by 30 percent in firefighters but no formal comparison was carried out.	-

Author	Type of Study	Population	Findings	Quality Assessment
			Although the paper does review a number of studies, it does not synthesise the data in any way.	
Tsai, *et al.*, (2015)	Case-control Study	Firefighters	This is a case-control study using California Cancer Registry data, comparing all cancers with 10 or more cases among firefighters with control cancers with little or no association with firefighting. The cohort included 3996 male firefighters Analyses were carried out for all firefighters, white firefighters and firefighters of 'other' race/ethnicity. Among all firefighters, elevated risks were found for melanoma (OR=1.8, 95% CI 1.4-2.1), multiple myeloma (OR=1.4, 95% CI 1-1.8), acute myeloid leukaemia (OR=1.4, 95% CI 1-2), oesophageal cancer (OR=1.6, 95% CI 1.2-2.1), prostate cancer (OR=1.5, 95% CI 1.3-1.7), brain (OR=1.5, 95% CI 1.2-2) and kidney cancer (OR=1.3, 95% CI 1-1.6). Among 'other' race/ ethnic groups increased risks were found for tongue cancer (OR=4.57, 95% CI 1.23-10.35), melanoma (OR=4.51, 95% CI 1.85-10.97), prostate cancer (OR=2.42, 95% CI 1.53-3.84), testicular cancer (OR=3.73, 95% CI 1.26-11.02), bladder cancer (OR=2.37, 95% CI 1.05-5.33), kidney cancer (OR=2.59, 95% CI 1.4-4.8), brain cancer (OR=3.58, 95% CI 1.65-7.74), non-Hodgkin's Lymphoma (OR=2.17, 95% CI 1.2-3.92), multiple myeloma (OR=3.77, 95% CI 1.91-7.44), Chronic lymphoid leukaemia (OR=7.04, 95% CI 2.99-16.56) and chronic myeloid leukaemia (OR=4.91, 95% CI 1.84-13.12).. Some suggested mechanisms were also made in the paper including prostate cancer (increased screening), melanoma, sun exposure and exposure to PAH,	-

Author	Type of Study	Population	Findings	Quality Assessment
			PCBs, aromatic hydrocarbon and heavy oil and oesophageal cancer due to fire suppression and overhaul).	
Wirth, *et al.*, (2013)	Review	Police Officers	This was a review where the relevant databases were searched systematically but there was no attempt made to synthesise the data mainly due to the quality of studies identified. The paper did identify in police officers significant increases in mortality due to all cancer, digestive organ malignancies and oesophageal, colon, kidney, bladder, brain, lymphatic, haematopoietic tissue, endocrine gland, breast, testicular, melanoma and Hodgkin's disease although there were noteworthy limitations among most of the studies reviewed (e.g. lack of exposure assessment, lack of control for confounding factors). There appeared to be a dose response linked to number of years in a few of the research papers reviewed.	-
Wong & Gomes (2010)	Review	Firefighters	There has been some research on firefighter prostate cancer levels but few reviews on the topic. This paper focuses on finding whether there is a correlation between firefighting occupation and levels of prostate cancer. As well, this paper notes potential carcinogens within the firefighting occupation Five papers were included in this review; these papers used different methods to obtain the cases and controls for the study. The papers also used different controls for comparison. The included papers found in the search supported a positive correlation between exposures in firefighting occupations and the level of prostate cancer.	+

Author	Type of Study	Population	Findings	Quality Assessment
			The two chemicals that were suspected carcinogens in these studies were Poly-aromatic hydrocarbons (PAH) and fire smoke	
Yip, *et al.*, (2015)	Cohort Study	Emergency Medical Service workers	The aim of the paper was to describe the health burden among Fire Department of the City of New York (FDNY) emergency medical service (EMS) workers and examine its association with work at the World Trade Center (WTC) disaster site. In this observational cohort study, we used FDNY physician diagnoses to estimate the cumulative incidence of physical health conditions including rhino sinusitis, gastroesophageal reflux disease (GERD), obstructive airways disease (OAD) and cancer among EMS workers and demographically similar firefighters who were active on 11 September 2001 (9/11) Among 2281 EMS workers, the 12-year post 9/11, the cumulative incidence of cancer 3.1% which was similar to that among unexposed workers (3.4%).	+
Zeig-Owens *et al.*, (2011)	Cohort Study	WTC Firefighters	This paper examined cancer incidence and potential exposures in the seven years after 9/11 including health data collected before this date in a cohort of 9853 male firefighters. Cancer cases were confirmed with cancer registries or other appropriate documentation. Compared with the general male population in the USA with a similar demographic mix, the standardised incidence ratios (SIRs) of the cancer incidence in WTC-exposed firefighters was 1.10 (95% CI 0.98–1.25). When compared with non-exposed firefighters, the SIR of cancer incidence in WTC-exposed firefighters was 1.19 (95% CI	++

Author	Type of Study	Population	Findings	Quality Assessment
			0.96–1.47) corrected for possible surveillance bias and 1.32 (1.07–1.62) without correction for surveillance bias.	

Phase 2: Evaluation of cancer risks associated with Firefighting

7 Phase 2: Introduction

Phase 1 of the study examined the epidemiological evidence for the incidence of specific cancers among firefighters. Based on the results from meta-analyses taking into account the results from individual studies, six types of cancer were identified for which evidence existed for a positive association with firefighting, although the relative risks were usually relatively modest. These are presented in Table 3. While there was no evidence of an association between firefighting and lung cancer, a single study of lung adenocarcinoma reported a significant incidence ratio among Danish firefighters of 1.90 (1.09-3.80).

Table 3 Cancers identified as having a positive association from epidemiological review meta-analysis

Cancer	Fixed Effect or Random Effects	Meta-RR	95% CI for meta-RR
Colon	Random	1.21	1.11-1.31
Rectal	Random	1.15	1.04-1.27
Melanoma	Fixed	1.39	1.27-1.52
Prostate	Random	1.15	1.05-1.26
Bladder	Random	1.15	1.02-1.30
Non-Hodgkin's Lymphoma	Fixed	1.13	1.04-1.23

RR – Relative Risk

Within this report the occupational risk factors associated with these cancers are examined and consideration given to whether these risk factors are present for firefighters. The next section describes the methodology that was used. It has been suggested that radio-frequency exposure may be a factor in the occurrence of cancer among firefighters. However, this has not been included in this report as current exposure duration to relevant equipment is too recent to enable studies to detect any associations with outcomes which generally have a long latency period, and there is currently insufficient evidence that EMFs cause cancer in adults.

However, the context of firefighting also needs to be reiterated at this point. Firefighters are involved in firefighting within buildings, woodland fires, vehicle extrications and in the USA, also take on the dual role of being a paramedic. The data also represents an international perspective and it should be borne in mind that there are different work practices, different levels of protection and different work processes between national borders.

In relation to how long or how often firefighters are involved in fires, IARC (2010) suggest that the time spent is between 0.75% and 2.7% of their working time over the course of a year.

8 Phase 2: Methodology

The approach taken was:

i) to examine the factors that the research literature indicates are linked to the development of specific forms of cancer and
ii) to examine (within the existing body of research) whether firefighters are exposed to these risk factors.

Studies of cancer in firefighters are largely predicated on the assumption that such cancers are caused by exposure to carcinogenic materials during work activities. At the time (2010) that IARC drew their conclusions on firefighters and cancer, they considered that: “Firefighters are exposed to many toxic combustion products, including many known, probable or possible carcinogens”. More recently, Fabian et al (2010) reported on detailed explorations of the numerous harmful substances, including known carcinogens, encountered in the aftermath from fires. The authors measured gas, particulates and other exposures from residential structural fires, car fires, simulated real-scale fire tests, and material-based small-scale fire tests.

This present report takes into account evidence regarding the known hazards to which firefighters are exposed, drawn from the existing research literature and from other reputable data sources, including the International Agency for Research into Cancer, Cancer Research UK, the National Institutes for Cancer (USA) and Australian cancer data sources. Further searches were carried out of the existing literature to identify whether additional information of relevance was available. The collective evidence from these various sources was used to assess the likelihood of occupation as a firefighter being a cause of the specific cancers examined.

9 Phase 2: Findings for specific cancers

9.1 Colon and rectal Cancer

Colon cancer and rectal cancer have differing aetiologies, and the data on these was split in the phase 1 report. However, wider data sources tend not to differentiate between the two, making it difficult to distinguish potential relationships between these cancers and occupation as a firefighter.

From the phase 1 report, a positive association was seen between colon cancer and occupation as a firefighter, with a meta RR=1.21 (95% CI 1.11-1.31) and for rectal cancer, with a meta RR=1.15, (95% CI 1.04-1.27).

The IARC monograph provides no relevant data in relation to colorectal cancer (collectively) or colon and rectal cancers separately and exposure to specific substances.

According to Cancer Research UK there were 41,265 new cases of colorectal cancer amongst the general UK population in 2014. Their data estimates that 54% of these cases were regarded as attributable to preventable causes, with 13% related to being overweight or obese, 12% to a lack of fibre in the diet and 21% from eating processed or red meat (Cancer Research UK 2016). In the general population the lifetime risk of bowel cancer for women was 5.47% and for men 7.27% within the UK (Cancer Research UK 2016). It is not possible to determine the extent to which these factors can be applied to an increased extent in firefighters and which may therefore provide some explanation of the observable excess amongst this group.

From the literature, the only occupational association identified with colorectal cancer and work is that of asbestos exposure. Offerman et al. (2014) identified that bowel cancer risk may be higher in individuals with prolonged and high levels of exposure to asbestos.

Clearly, firefighters are potentially exposed to asbestos, in particular when dealing with building fires and their aftermaths. When examining the data published by Daniels et al (2013) in US firefighters, mortality rates for mesothelioma in the cohort (1950-2009) were calculated as SMR=2 (95% CI 1.03-3.49) and the incidence rate (1985-2009) as SIR=2.29, (95% CI 1.60-3.19). The authors do identify that for those in the 1985-2009 cohort, 88.6% (n=31) were pleural mesothelioma registrations. Pukkula et al, (2014) in their Scandinavian study following firefighters from five countries for 45 years identified an excess of mesothelioma cases. This was only statistically significant in the older firefighters age group of 70+ (SIR=2.59, 95% CI 1.24-4.77). The authors suggest that this may be due to the long latency associated with exposure to asbestos (and it could also reflect different standards relating to protection in their earlier years of service).

However, within Phase 1 of the study, no consistent elevated risk for mesothelioma or lung cancer was observed in the meta-analyses of fire fighters. The reasons for this are unclear, but could be due partly to international differences in regulation around the use of asbestos as a building material; as well as changes in the use of protective equipment during firefighting and overhaul.

Hence, from the available evidence it is not possible to conclude that asbestos or any other particular occupational exposure is associated with the observed increased risk of colorectal cancer in firefighters. Further research is required that specifically examines colon cancer and rectal cancer separately within this occupational group.

9.2 Melanoma

The phase 1 epidemiological review identified a meta RR=1.39, (95% CI 1.27-1.52) for melanoma. When we examine UK data in relation to melanoma, it is estimated that cases of melanoma could be attributed to identified avoidable causes in 90% of males and 86% of females. Within the UK the lifetime risk of melanoma is 1.85% for women and 1.94% for men (Cancer Research UK 2016).

Exposure to ultraviolet radiation (UVR) from the sun has been classified by IARC as a cause of both melanoma and non-melanoma skin cancer (IARC 1992). Since the 1970s, rates of skin melanoma have increased in the UK by 360%, potentially due to increased sun exposure through holidays. This increase has been higher among men than women. Although the use of ultraviolet-emitting devices such as sunbeds was recognised as a potential carcinogen in 1992 (IARC 1992), melanoma risk in those who have ever used a sunbed is increased by between 16% and 25% indicating that sunbed use alone does not account for any excess.

Occupational factors have also been examined in relation to skin melanoma, and Cancer Research UK have identified that coal tar pitch, soot, mineral oils, shale oils, arsenic and inorganic arsenic compounds have each been classified by IARC as causes of skin cancer (Cogliano et al 2011). In examining the IARC monograph on shift work, painters and firefighting, dermal exposure to poly-aromatic hydrocarbons (PAHs) was identified as a potential contribution to melanoma amongst firefighters. This was based on data which examined exposures from structural and wildfire smoke.

Fabian et al (2010) reported that PAHs were identified in the smoke samples they analysed from their fires, but were also found on the gloves and hoods worn by the firefighters. The analysis found PAHs at a higher concentration on gloves when compared to hoods suggesting contamination through direct contact rather than airborne sources. Clearly, the presence of such substances on gloves and other equipment provides evidence for potential exposure. However, it is not clear to what extent the contamination is transferred to the skin resulting in actual exposure.

Fent et al (2014) examined firefighters' exposure during controlled fire suppression exercises while the firefighters were wearing new or laundered fire kit. The study examined exposure to PAHs and benzene and used biomarkers in urine, skin swab tests and exhaled breath samples. The analysis identified that post-exposure benzene levels in breath samples were significantly higher than pre-exposures. In relation to dermal exposure, levels of PAHs from neck swabs were found to be significantly higher post-exposure when compared to pre-exposure. This study ensured firefighters wore breathing apparatus throughout the exercise and did not remove protective equipment until at some distance from the fires. It does suggest that dermal exposure is a route to absorb both PAHs and benzene, and for PAHs, most specifically due to a lack of protection in the neck region.

In conclusion, the observed increased risk of melanoma in firefighters may be associated with sunlight exposure or with dermal exposure to combustion soot and its various components. While protective equipment and clothing afford some protection to firefighters, there is a concern that dermal absorption of some substances from areas that are not protected (such as the neck), or at least have not been protected in the past, may be a risk factor for firefighters. Furthermore, the increased contamination of gloves (Fabian et al 2010) may also have an impact and glove liners may be able to reduce this exposure route. Sunlight exposure may occur during outdoor activities when protective equipment is not worn consistently, e.g. during the aftermath of fires, such as when damping down wildfires.

9.3 Prostate Cancer

The meta-analysis carried out in phase one of the study calculated a meta-RR of 1.15 (95% CI 1.05-1.26) for prostate cancer. This suggests a possible modest association between prostate cancer and occupation as a firefighter.

The IARC monograph on night working, painters and firefighters found prostate cancer in firefighters to be associated with exposure to particles (including diesel exhaust), and possibly also with exposure to PAHs (IARC 2010).

Rao et al (2015) carried out a meta-analysis of night shift work and its association with prostate cancer. This study was not specifically related to firefighting but examined the incidence of prostate cancer in the general population. The meta-analysis resulted in a meta-RR of 1.24 (95% CI 1.05-1.46; p=0.011). In addition to this, a dose-response relationship was identified that found that working night shifts for five years or more was significantly associated with a small (2.8%) increase in the risk of prostate cancer. Clearly, some firefighters do shift work and therefore any increase in risk amongst firefighters could, at least in part, be attributable to this factor. However, there is not currently sufficient information on this factor to provide a reliable estimate of this contribution.

The evidence in relation to lifestyle factors is not clear and current data from Cancer Research UK does not highlight further evidence of other associations, although there has been substantial research into the potential causes of prostate cancer. The lifetime risk of prostate cancer in men is 13.72% in the UK (Cancer Research UK 2016).

In their studies of substances in smoke from fires, Fabian et al (2010) found that individuals were exposed to PAH from soot, finding this in the smoke of fires and on the gloves and hoods worn by the firefighters.

One of the main issues in our understanding of exposures and mechanisms of cancer is how the exposure could potentially result in the cancer. PAHs include a number of different chemicals which are likely to have different routes into and within the body and potentially different actions in body tissues. While skin absorption appears to be rapid, this varies with the particular compound being studied. A further complexity lies in understanding how any such actions lead to prostate cancer. While IARC (2010) acknowledge that there is a possible link between prostate cancer and PAH exposure, the biological mechanism through which this occurs is not currently understood.

In summary, there is an apparent excess risk of prostate cancer amongst firefighters. While shift work (which also leads to an increased risk of prostate cancer) might account for some of this excess there is evidence that PAHs (to which firefighters are potentially exposed) can also result in an increased risk of prostate cancer.

9.4 Bladder Cancer

The meta-RR calculated from the previous epidemiological data was equal to 1.15, (95% CI 1.02-1.30).

A number of chemical exposures of possible relevance have been found to be associated with bladder cancer. From the IARC monograph these include PAHs, acrolein and diesel exhaust (IARC 2010). Cancer Research UK also identifies a number of chemicals associated with bladder cancer including PAHs, but also aromatic amines, arsenic, and tetrachloroethylene (Cancer Research 2016).

The lifetime risk of bladder cancer in the UK is 0.95% for females and 2.62% for males. Lifestyle factors have been found to be associated with bladder cancer, most specifically smoking which is associated with an estimated 37% of UK cases (Cancer Research UK 2016). It is not known whether firefighters are more likely to smoke than the general population and whether this could explain any proportion of the excess risk of bladder cancers amongst this group, but this is unlikely to be a major factor, as the results of the meta-analyses did not suggest an overall increased risk of lung cancer amongst firefighters (which would be likely to result from more smoking amongst this group).

As noted earlier, Fabian and co-workers identified PAHs both in the smoke produced by the set fires and on gloves (especially) and hoods worn by firefighters. The authors also identified arsenic in some instances, at levels that sometimes exceeded recommended exposure levels.
In summary, there is an increased risk of bladder cancer amongst firefighters. Although bladder cancer can be attributed at least in part to smoking, exposure to certain chemicals including some found in the smoke from fires, can also lead to an increased risk.

9.5 Non-Hodgkin's Lymphoma (NHL)

The previous meta-analysis calculated a meta-RR=1.13 (95% CI 1.04-1.23). Among the general population in the UK there were 13,604 cases in the UK in 2014, with a lifetime risk of 1.73% in females and 2.12% in males (Cancer Research UK 2016). When examining the population risk factors for NHL, it is estimated that 6% are attributable to preventable causes and that the risk is increased in individuals who are overweight or obese.

With regard to occupational exposures, working with rubber is a recognised cause of NHL (Coglioni et al 2011). In addition, other chemical agents such as benzene, ethylene oxide, tetrachloroethylene and trichloroethylene have been identified as possible risk factors for NHL, although this is based on limited evidence. Furthermore, IARC identified that exposure to diesel exhaust is possibly associated with NHL.

Fabian and colleagues (2010) found benzene in some smokes and Guidotti (2014) states that trichloroethylene can be found in smoke, although the text does not include any documentary sources for this.

In summary, it appears that there is a small increased risk of NHL amongst firefighters. There is evidence that this can be caused by a number of substances, including some such as benzene and trichloroethylene which can be found in some smokes.

9.6 Lung Adenocarcinoma

While associations between lung cancer and firefighting were not found to be significantly positive, one study of Nordic Firefighters study identified that there was a significant association between firefighting and lung adenocarcinoma among Danish firefighters (Pukkala, 2014). These results have not been identified elsewhere and this may be due to lung cancer data not being broken down into different types of lung cancer. Associations between lung adenocarcinoma have been found in relation to smoking, exposure to second-hand smoke, radon, asbestos, silica, diesel fumes and air pollution.

10 Phase 2: Discussion

First of all, it should be highlighted that the relative risks identified within the epidemiological review are generally quite low. The highest meta RR was observed for melanoma at 1.4. For the other forms of cancer, the meta RR was 1.2 or less. For most forms of cancer (with the exception of mesothelioma) there are multifactorial causes for the disease, which include a mixture of genetic, lifestyle and environmental factors. Combined with the highly variable nature of the work that firefighters do and the environments that they work in, it is unlikely that strong associations with individual occupational exposures can be identified. Furthermore, firefighters often have second jobs where they may be exposed to different hazards (IARC 2010). Although numerous studies have reported on the potential toxic constituents of smoke it should be acknowledged that firefighters generally spend very little of their time fighting fires or dealing with their immediate aftermath. The 2010 IARC review provides a useful overview of this.

Assuming working in or in close proximity to smoky environments results in exposure to carcinogenic materials the next challenge is to consider how such substances enter the body. There does not appear to be a significantly elevated risk of lung cancer among firefighters (shown most recently by Bigert et al, 2016), which suggests that, as many of the substances in smoke are known to cause lung cancer, the inhalation route is not an important route of exposure. However, there is some evidence that the dermal route may be a potentially important route, which is also consistent with the observed excess risk of melanoma referred to earlier.

While the studies cited in the document do measure levels of different particles and substances, these are experimental set-ups and each fire is likely to give a different exposure depending on place, substances burned and ventilation. This has been part of the challenge in monitoring exposures within firefighters and is an area that is constantly updating. It is also important to understand the different roles that firefighters have when working, as not all of their activities necessarily involve fires and, where they do, the nature of the fires and of their roles varies considerably. This includes (but is not limited to) dealing with building fires (domestic and business), clearing up after fires (overhaul), wildfires (e.g. brush or forest), car fires and extrication from vehicles. Furthermore, there are differences in firefighting equipment and firefighting methods used internationally. Although some epidemiological studies have attempted to make allowances for this most have treated firefighters as a homogenous group.

While firefighters have access to protective equipment there are still questions as to how consistently such equipment is used and whether respiratory protection is used during overhaul. Each country is likely to have its own regulations with regard to this. Furthermore, the long latency period for most forms of cancer means that most of the studies encompass periods of work in earlier years where the protection available (and, anecdotally at least, attitudes towards the use of that protection) was somewhat different to that in use now. It is necessary therefore to reflect on what working practices would have been and what protection would have been available in the early years covered by such studies, during which time the probably most influential exposures potentially occurred.

The use of respiratory protection is an essential part of firefighting equipment (at least amongst modern firefighting practices), but the research to date also shows other potential exposure routes including dermal exposure. In relation to this there appears to be a growing awareness that secondary exposures, from contact with contaminated equipment, clothing and other PPE may be important sources. However, although skin exposure may prove to be an important avenue for contamination not all substances will be taken up through the skin and further research is required for such substances to explain or account for any potential contribution to the overall burden of cancer amongst firefighters.

11 Phase 2: Conclusions

Firefighters are potentially exposed to many different substances in the work that they do. However, it is clear that the nature and extent of such exposures varies tremendously between individuals and, as a result, it is difficult to identify particular exposures in respect of cancer causation. Furthermore, our understanding of the mechanisms of cancer causation associated with these different substances is limited. The causes of most cancers are multifactorial, often including both lifestyle factors (such as smoking and diet), as well as occupational factors not related to substance exposure such as shift work or having a second job, in addition to any arising from substance exposures during firefighting activities, chemical spillages, etc. Given the relatively modest nature of any elevated risk identified it is likely that the contribution of exposure to any particular chemical substance is likely to be even more modest.

There are known associations between PAHs and melanoma, bladder and possibly prostate cancers. However, the sources of PAHs in any fire environment can be numerous and without specific environmental monitoring it is impossible to state the sources. Exposure to diesel fumes was also identified as being associated with prostate and bladder cancer and possibly associated with non-Hodgkin's lymphoma and lung adenocarcinoma.

What is clear is that respiratory protection for firefighters both during firefighting activities and overhaul is essential. However, we still only have limited understanding of the impact of dermal exposure routes for carcinogens and this is an area that needs further research, as there have been fewer measurements of dermal contamination reported and currently not all exposures that have been measured have been evaluated for dermal uptake. While reviewing epidemiological exposures as a firefighter and their cancer outcome is a broad task more emphasis should be put on defining specific research questions. Such research questions could include:

- What are the potential causal factors of colon and rectal cancers studied separately rather than grouped as colorectal cancer?
- What are the most commonly experienced exposures of firefighters in different firefighting scenarios?
- What is the relative importance of inhalation and dermal routes of exposure among firefighters?
- Which interventions would be most effective in reducing exposures to PAHs and diesel fumes among firefighters?

12 Phase 2: References

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Phase 3: Evaluation of Firefighters' exposure to PAHs

13 Phase 3 Introduction

Phase 1 of the study examined the epidemiological evidence for the incidence of specific cancers among firefighters. Based on the results from meta-analyses taking into account the results from individual studies, six types of cancer were identified for which evidence existed for a positive association with firefighting, although the relative risks were usually relatively modest. These six are presented in Table 4. While there was no evidence of an association between firefighting and lung cancer, a single study of lung adenocarcinoma reported a significant incidence ratio among Danish firefighters of 1.90 (1.09-3.80).

Table 4: Cancers identified as having a positive association from epidemiological review meta-analysis

Cancer	Fixed or Random Effects	Meta-RR	95% CI for meta-RR
Colon	Random	1.21	1.11-1.31
Rectal	Random	1.15	1.04-1.27
Melanoma	Fixed	1.39	1.27-1.52
Prostate	Random	1.15	1.05-1.26
Bladder	Random	1.15	1.02-1.30
Non-Hodgkin's Lymphoma	Fixed	1.13	1.04-1.23

RR – Relative Risk

However, the context of firefighting also needs to be reiterated at this point. Firefighters are involved in firefighting within buildings, woodland fires, vehicle extrications and in the USA, also take on the dual role of being a paramedic. The data also represents an international perspective and it should be borne in mind that there are different work practices, different levels of protection and different work processes between national borders

In relation to how long or how often firefighters are involved in fires, IARC (2010) suggest that the time spent is between 0.75% and 2.7% of their working time over the course of a year.

Following the literature review and meta-analysis, a second report considered the occupational risk factors associated with these cancers with consideration given to whether these risk factors are present at non-trivial exposure levels for firefighters.

From this Phase 2 work, it is evident that firefighters are potentially exposed to many different substances in the work that they do. However, it is clear that the nature and extent of such exposures varies substantially between individuals and, as a result, it is difficult to identify particular exposures in respect of cancer causation. Furthermore, our understanding of the mechanisms of cancer causation associated with these different substances is limited. The causes of most cancers are multifactorial, often including both lifestyle factors (such as smoking and diet), as well as occupational factors. Occupation factors can be unrelated to substance exposure, such as shift work, as well as arising from substance exposures during firefighting activities, chemical spillages, etc. Given the relatively modest nature of the elevated cancer risk identified, it is likely that the role of exposure to any particular chemical substance in cancer causation is also likely to be small.

The results of the investigation indicated that three of the six cancers were associated with exposure to PAHs (melanoma, bladder and possibly prostate cancers), with other associations apparent with diesel (prostate and bladder cancer) and sunlight exposure (melanoma). Within the current report we look in more detail at the potential exposure of firefighters to PAHs as these were the most commonly identified potentially causal exposures. It should be noted that it is likely that all burning substances that contain aromatic compounds (including, but not limited to, building materials, furnishings, trees and vehicles) will emit PAHs. In addition, the sources of PAHs in any fire environment can be numerous and without specific environmental monitoring it would not be possible to identify these sources. The nature of fires in terms of the substances burning and consequential exposures to potentially toxic combustion products will have changed over time, with new building materials, building furnishings and contents and an increased use of plastics and other man-made materials.

What is clear is that respiratory protection for firefighters both during firefighting activities and overhaul is essential. However, we still only have limited understanding of the impact of dermal exposure routes for carcinogens and this is an area that needs further research, as there have been fewer measurements of dermal contamination reported and currently not all exposures that have been measured have been evaluated for dermal uptake.

The Phase 3 work aimed to examine the following research questions.

1. What sources of PAHs are firefighters exposed to?
2. What is the route of exposure for firefighters?
3. What assessments have been made in relation to materials and combustion?

14 Phase 3: Methodology

The approach taken was the following:

1. Identification of relevant literature
2. Identification of exposure routes and measurement
3. Identification of relevant research into materials and combustion

While the previous reports had used a full search strategy to identify research involving firefighters, a different approach was taken with this phase of work. Search terms were developed and included the following:

- polyaromatic hydrocarbons
- PAHs
- Exposure
- Emissions
- Dermal
- Inhalation
- Combustion
- Diesel
- Coal-tar
- Coke production
- Coke ovens
- Polyaromatic compounds
- PACs
- Wildfire
-
- Wood smoke

Searches were carried out on the following databases:

- ABI Inform
- Medline
- Proquest Biological and Health Science Professional
- Proquest Environmental Science Professional
- SciSearch
- Google Scholar

Websites searched included the following:

- NIOSH
- European Agency for Safety and Health
- HSE

When searches were completed, titles and abstracts were stored using RefWorks reference management software. This enabled the full list of publications to be screened to ensure that they were relevant to the research questions. Where there was no clarity from the title and abstract, the full publication was obtained.

15 Phase 3: Results

15.1 Papers identified

A total of 143 papers were identified from the searches. Titles and abstracts were screened and this resulted in the procurement of 36 papers for the review. In total, after data extraction, 18 papers were included in the review. The included papers have been broken down into specific fire environments to gain an insight into question 1, what sources of PAHs are firefighters exposed to.

15.2 What sources of PAHs are firefighters exposed to

This section has been broken down into different environments in which firefighters work. Several papers have collected data over different environments, hence they are included in more than one section.

15.2.1 Exposure during live fires

Exposure measurements during live or actual fires are difficult to carry out as there can be a lack of consistency in data collection due to the length of the firefighting activity. However, three papers were identified that examined exposure to PAHs during firefighting.

Fabian et al., (2014), wanted to fully understand what firefighters were exposed to in smoke (1). Their study recruited four firefighters and measurements were made over 25 fires, which ranged in duration from 17 minutes to 37 minutes. The measurements made included wipe samples of clothing, PPE and skin.

PAHs measured on jackets were found to increase in level after attendance at the first fire, the same was found for other PPE. The PAH with the highest concentration was fluoranthene. Higher levels of contaminants were associated with the specific tasks the firefighters were carrying out including ‘inside attack’ and ‘inside search’ which resulted in the highest levels of contamination. Higher levels of PAHs on hand skin were found on those tasked with ‘inside search’. For the neck samples, the highest levels were found on ‘outside vent’ which does suggest either hoods were not being worn or the PAHs are permeating the hoods. However, 50% of participants did not have detectable PAHs measured on their necks.

The study by Fabian et al highlights that field decontamination of turnout gear can reduce PAHs contamination by 85%. However, the authors do recommend that consideration be given to cleaning fire kit between fires rather than wearing it more than once.

Keir et al, (2017) examined PAH exposure through both dermal routes and biomonitoring (2). The study of 27 firefighters and 17 office workers as controls, monitored individuals pre-shift and post-incident. PAHs and their metabolites measured as part of this study included naphthalene, fluorene, pyrene and benzo(a)pyrene as examples.

The results identified that in firefighters, compared to the control group, there was a significantly increased level of PAH metabolites in the post-incident group compared with pre-incidence and the control group. In relation to the dermal contamination, the paper highlights the increase in PAH metabolites found in the firefighter who did not wear a smoke hood, thus confirming dermal exposure as a potential route.

The study confirms that firefighting is associated with increased concentrations of urinary PAH metabolites. However, the authors do point out that more consideration is need to improve protection of the firefighting population by more effective PPE and decontamination procedures.

What the studies do confirm is that firefighters are exposed to PAHs during firefighting. However, identification of particular PAHs is made difficult as these will depend on the materials that are combusted during the fire. However, Keir et al, (2017) do point out that more consideration is needed in relation to the PPE worn by firefighters and decontamination of both the fire kit and the firefighters after firefighting.

15.2.2 Exposure during training fires

Firefighters are exposed to fire environments during training exercises and this appears to be an easier route to monitoring what particular chemicals individuals are exposed to.

Fent et al., (2013, 2017), carried out a cross-sectional study examining dermal exposure to PAHs during controlled burns (3,4). In their sample of 30 firefighters in six different fires (all of whom had reached trainer grade within the service), breath, skin wipe and urine samples were taken from each participant and air measurements were also made.

The air samples did find airborne PAHs and as a grouped concentration, this was above recommended occupational exposure limits (USA) during the fire stage. Concentrations were also raised during overhaul. The types of PAHs included Napthalene (51% of total concentration), benzo(a)pyrene (1%), chrysene (1%) and several others.

Dermal wipe samples were taken for the neck, arm and scrotum. No differences were found pre and post fires apart from the neck area where there was a significant increase ($P<0.02$) between pre and post median PAH levels in one group (3). It was suggested that this was due to shorter length smokehoods that could not be tucked into jackets.

Exhaled breath samples also found an increase pre and post exercise for the compounds of benzene and toluene. However, the authors do point out that PAHs exposure can occur through other routes including exposure to diesel and food.

Fent et al, (2013) highlight the importance of protection for firefighters including wearing full PPE during firefighting and overhaul, introducing ventilation where possible, removing SCBA and hood last, storing used kit outside the fire engine and washing as soon as possible after a call out.

Keir & Logan (2015) examined PAHs exposure during live fire exercises in Australia (2). Their study examined air concentrations of PAHs and examined exposure on the external side of fire kit and the inside of fire kit. Personal air samples were taken five times outside the fire kit and five times inside the fire kit. Swatches were attached to the fire kit to enable measurement of exposure on materials.

The results identified that total PAH concentrations ranged from 430 µg/m3 to 2700 µg/m3 outside the instructors' firefighting ensembles, and from 32 µg/m3 to 355 µg/m3 inside the instructors' firefighting ensembles. Naphthalene, phenanthrene and acenaphthylene were the highest concentrations during the live fire exercises, but benzo[a]pyrene was the greatest contributor to the toxicity of the PAH mixture both inside and outside the structural firefighting ensembles. Deposition of PAHs onto the structural firefighting ensembles was measured at between 69 and 290 ng/cm2 , with phenanthrene, fluoranthene, pyrene, and benzo[a]anthracene detected on all samples. This study highlights that PAHs are able to get inside fire kit, however concentrations measured internally were significantly lower than external concentrations.

Fernando et al., (2015) examined PAHs exposure during wood burning in training houses in Canada (5). The study examined exposure to PAHs during wood burning at four fire stations where inhalation, dermal and biomonitoring took place. A total of 28 firefighters took part in 5 exercises.

Naphthalene, phenanthrene, fluoranthrene, and pyrene were the predominant PAHs measured in air samples. Skin measurements identified that the fingers swabs had the highest concentration of chemicals on them and this is thought to be related to removing the SCBA and smoke hood.

Stec et al., (2017) examined PAHs exposure in firefighters during training exercises (6). Based on the Environmental Protection Agency (EPA) 16 PAHs, dermal samples were quantified pre and post training exercises. The skin sites chosen for the samples were the back and front of the neck, the jawline and the hands. Samples were also taken from clothing and PPE. The training exercises lasted approximately 60 minutes and samples were taken from four firefighters during each exercise.

PAHs concentrations were higher post the fire exercise with the highest concentrations on the hands. PAHs concentrations on the clothing and face masks were also higher post-exercise. Interestingly, the PAHs concentrations on the face masks were higher pre-exercise. The authors point out that this may indicate the current cleaning regime is not adequate to remove such chemicals.

15.2.3 Exposure during Wildland fires

Wildland firefighting has also been examined in relation to PAHs exposure. Robinson et al., (2008), examined exposure to PAHs during pile burning (planned burning) of pine trees in the USA to find out if exposure to PAHs while burning was associated with increase in urine samples (7). Measurements were made of three job categories including burn boss, igniter, monitor and patroller. Samples were taken from twelve firefighters via air sampling and urine tests.

Personal PAH exposures were detectable for only 3 of 16 PAHs analysed and included naphthalene, phenanthrene, and fluorene, all of which were identified only in vapour phase. There were no significant increases in urinary metabolites pre and post burning. However, the authors noted that firefighters were able to mobilise themselves away from the smoke while carrying out the burning.

Navarro et al., (2017) examined PAHs exposure for twenty-one firefighters involved in two wildland fires compared with four firefighters carrying out prescribed burns(8). Seventeen measureable PAHs were identified during the wildland fires.

Naphthalene, retene, and phenanthrene were consistently the highest measured PAHs. PAHs concentrations were found to be higher at wildland fires compared to prescribed burning. The tasks the firefighters were carrying out also influenced exposure with those having most direct contact with smoke, experiencing higher levels. The concentrations of PAHs measured did not exceed USA occupational exposure limits

Adetona et al., (2017) examined urinary biomarkers for PAHs exposure in firefighters involved in wildland firefighting(9). During the burn season, a total of 56 pre and post samples were obtained from 14 firefighters from 16 different burns. The study identified that the urinary levels of PAHs were higher than the general US population during the burn season. When comparing pre and post burning levels of urinary metabolites, these were significantly higher ($P<0.0001$ ranging from 83-323% higher) post burning. The paper indicates that wildland firefighters are exposed to PAHs during the burn season.

15.2.4 Exposure during Overhaul

Bolstad-Johnson et al., (2000) identified that overhaul is a stage of firefighting where the fire suppression has been completed but firefighters are still searching the structure for any hidden fires or hot embers. It is estimated that this stage of work lasts on average 30 minutes (10); however, this may be extended as a result of searches for casualties.

Within this study, 25 overhaul events after structural fires were monitored for PAHs and other chemicals. Personal sampling was carried out by a firefighter wearing the monitoring equipment and shadowing a working firefighter. The analysis identified 17 PAHs including benzene which exceeded USA short-term occupational exposure measures at two fires but no other limits were exceeded. The authors expressed surprise that there were PAHs in the overhaul environment as there was no smoke present.

Wyant (unknown) in a non-peer-reviewed report aimed to examine the constituents in smoke from 4 pre-set fires during overhaul (11). The study was carried out to identify if SCBA should be worn during overhaul. The methodology of the study showed that for samples to be taken the fire should be set within a structure with a wooden frame, the structure should have been occupied and contain furnishings including floor and window coverings and the structure should have suffered at least one room with 75% fire damage.

The study involved air sampling during overhaul and identified that benzene (15-132 ppbv), toluene (8-40 ppbv) and styrene (5-85 ppbv) were found during three of the four overhaul scenarios. The study did result in the recommendation that SCBA should be worn during overhaul due to the results of exposure to PAHs and other chemicals.

Baxter et al., (2014) report on a pilot study to examine PAHs and particulate exposures during overhaul at five live fire events (12). Air measurements and skin wipe samples were made during the study.

During overhaul, although 17 PAHs were measured, naphthalene and acenaphthylene were the two that were detected. For naphthalene, this was detected at seven out of eight overhaul events. In this study, all mean concentrations were below 1 µg/m3.

From the wipe samples taken after the fire events, benzo (b,j,k) fluoranthene was found in 65% of samples and pyrene was found in 30% of the wipes. Other compounds detected included chrysene, phenanthrene, benzo(a)pyrene and benzo(e)pyrene. The results from the Baxter study were used to recommend that PPE and SCBA should be worn during overhaul activities.

15.2.5 Exposure in Fire Stations

Exposure to PAHs in fire stations have also been addressed by a number of authors. Baxter et al., (2014) studied PAHs exposures during overhaul and within two fire stations (12). Measurements in the fire stations were taken in the kitchen, sleeping area and the truck bay. The researchers aimed to measure 16 PAHs in the fire stations. The results identified that only naphthalene was found in samples in one fire house in both the kitchen and the truck bays (garage). The authors recommend that based on this and data collected on other chemicals that decontamination of both kit and firefighters should happen quickly after a fire event.

Oliveira et al., (2017) examined PAHs exposures in eight fire stations in Portugal (13). The study examined 18 different PAHs via air sampling in the breathing zones in each of the stations. The results identified that the two rural fire stations had the lowest levels of PAHs. The most common PAH identified was naphthalene and none of the airborne exposures measured had PAHs levels above recommended exposure limits. However, when examining the differences between fire stations, the site of the fire station (rural vs urban), inappropriate building layout and the age of the building were all determinants of the levels of PAHs found.

Sparer et al., (2017) reports on a pilot study carried out in four US fire stations (14). The study aimed to examine PAHs levels in the kitchen, truck bay and just outside the fire station. The analysis of results identified that PAHs levels were highest in the truck bays when compared to the kitchen or just outside the fire station.

The study also highlights the need for preventive design in fire stations to prevent pollution in the truck bays leaking into the kitchen areas of the fire stations. The authors highlight the importance of fire station design to ensure separation between vehicles and living quarters. The study also highlights how small changes, such as having access to a professional washing machine, can ensure that fire kit is cleaned regularly.

Bott et al., (2017) examined PAHs exposures in eight fire stations in Australia (15). Sampling was carried out over the 10-hour period of a day shift with measurements made in the truck bay, the duty office, the dormitory and outside the fire station (15). PAHs exposures were averaged over the ten hour shift with pyrene, fluoranthene, anthracene, phenanthrene, fluorene, acenaphthene and naphthalene detected in measureable amounts.

Total PAHs measured in the duty offices ranged from 0.1-0.6 $\mu g/m^{-3}$, in the dormitories 0.1-0.9 $\mu g/m^{-3}$ and in the truck bays, measures exceeding the calibration limits of the monitoring equipment of 1 $\mu g/m^{-3}$. While the measures in the dormitories and offices did not breach US exposure limits, there are concerns in relation to the measures made in the truck bays. The authors conclude that specific considerations should be made for areas in fire stations where engines are run including specific ventilation and minimising air exchange between the engine bays and the rest of the fire station.

Stec et al., (2018) examined wipe and gas samples from two fire stations and fire engines attached to those fire stations(6). The results from the fire engines only found naphthalene, but concentrations were found to increase over time when measures were made after a fire incident.

The samples taken from inside the fire station included naphthalene, chrysene, benzo(a)anthracene, and benzo(b)fuoranthene.

15.2.6 Clothing and PPE Tests

Easter et al., (2016) examined clothing samples including the outer shell and inner linings to identify the composition of the soils found there (16). The samples were taken from seven sets of turnout gear that had been used over the preceding 5 years. Samples from the clothing were taken from areas known to have higher dermal absorption rates (collar, armpit, wrist crotch and wristlet).

The analysis for PAHs identified that for the substances, anthracene, benzo(a)pyrene, chrysene, fluoranthene, naphthalene, phenanthrene and pyrene; deposits were found on both the outer layer and the inner liner of the fire kit. Table 5 shows the measured levels from the clothing and highlight that there is both outer shell soiling as well as thermal liner soiling. This may indicate that the PAHs are being absorbed by the clothing then by the skin and this may be a dermal exposure pathway.

However, the clothing samples used within the study were cleaned on an annual basis. This is not necessarily the method used within other fire services where kit is cleaned after a fire event.

Table 5: PAHs Concentrations on Clothing Samples

Substance	Outer shell average concentrations (mg/kg) (SD)		Thermal liner average concentrations (mg/kg) (SD)		Outer shell 95th Percentile (mg/kg)	Thermal Liner 95th Percentile (mg/kg)
Anthracene	0.87	(0.6)	0.22	(0.1)	2	0.4
Benzo(a)pyrene	2.0	(2)	0.32	(0.2)	6.8	0.9
Chrysene	3.4	(4)	0.55	(0.4)	12	1.7
Fluoranthene	4.5	(4)	0.88	(0.6)	15	2.2
Napthalene	0.45	(0.1)	0.14	(0.05)	0.7	0.2
Phenanthrene	2.7	(2)	0.84	(0.5)	7.6	1.9
Pyrene	4.0	(4)	0.55	(0.5)	13	1.8

Alexander (2012), as part of a Masters degree examined clothing swatches from hoods, gloves and one coat and took wipe samples from inside SCBA faceplates(17). The study was focused on sampling for DEHP rather than PAHs but contamination for PAHs was found in the hoods, gloves (including outer and inner liner) and the coat wristlets. These included naphthalene, benzo(a)pyrene, fluoranthene and chrysene.

15.2.7 Summary and Conclusion

These studies show that firefighters are exposed to PAHs in different environments including live firefighting, training exercises, wildfire firefighting and within engine or truck bays. While specific sources of PAHs are not always identified within the research presented, their existence has been shown within the tasks that firefighters carry out, the training that they are required to do as well as during overhaul and within engine bays.

A summary of the measurements of PAHs is shown in Appendix 1.

15.3 What is the route of exposure for firefighters?

When examining the earlier stages of this work (Crawford et al 2016), it was suggested that respiratory protection in relation to lung cancer was having a positive effect. However, the research reported within this study has identified dermal exposure as a potential route. For example, wipe samples consistently found higher concentrations of PAHs pre and post fire exposure (1-3,6). The examination of clothing also highlighted the ingress of PAHs from outer layers to inner layers; although this was not tested in test fires or live firefighting(16)

It is unclear from the two studies that took wipe samples from face plates whether the potential exposure route is through dermal or inhalation exposure.

15.4 What assessments have been made in relation to materials and combustion

This report has not delved into particular tests in relation to specific materials, but has focused on the research in relation to actual exposure by firefighters in specific environments.

The research evidence has highlighted that exposure to PAHs occur in live fire exercises, training exercises and wildfire firefighting. While specific material tests may be relevant to other areas of research, in this case, firefighters will not know what they are likely to be exposed to in structural fires and the contents of the smoke will depend on the products within the structure and the contents of the structure. As this is often unknown, it is important that a precautionary principle be applied and fire kit and PPE used to protect firefighters.

16 Phase 3: Discussion

PAHs are in the atmosphere from a large number of sources, but for those measured in the reported research, it is important to stress that some may be more dangerous than others. Table 6 presents the PAHs measured within the research with their IARC grouping in relation to carcinogenicity. It is important to remember that these groupings may change in future as further research data becomes available.

Table 6: PAHs and IARC Grouping

PAHs identified in the research	IARC Grouping
Fluoranthene	3 Not classifiable as to its carcinogenicity to humans
Naphthalene	2b Possibly carcinogenic to humans
Fluorene	3 Not classifiable as to its carcinogenicity to humans
Pyrene	3 Not classifiable as to its carcinogenicity to humans
Benzo(a)pyrene	1 Carcinogenic to humans
Benzo(e)pyrene	3 Not classifiable as to its carcinogenicity to humans
Phenanthrene	3 Not classifiable as to its carcinogenicity to humans
Chrysene	2b Possibly carcinogenic to humans
Toluene	3 Not classifiable as to its carcinogenicity to humans
Acenaphthene	3 Not classifiable as to its carcinogenicity to humans

Information accessed on 17th March 2018
http://monographs.iarc.fr/ENG/Classification/ClassificationsAlphaOrder.pdf

The research reviewed does confirm that firefighters are exposed to a variety of PAHs in live firefighting, training exercises, wildfire firefighting, overhaul and within fire station engine bays. There also appears to be ingress into fire engines and office and dormitory areas in fire stations. However, the types of PAHs monitored in each of these settings varied and not all were grouping 1 in the IARC classification.

How often firefighters' kit is thoroughly cleaned also warrants discussion. Fabian et al., (2014) found that by carrying out decontamination on site, 85% of contaminants were removed(1).

However, within this study it was suggested that fire kit should be washed after every fire event. The practice of cleaning fire kit after each fire event is likely to vary by country but it would be recommended that this does occur.

Donning and doffing fire kit is another area where practices may differ between countries. The results from the studies reviewed would suggest that there is a need to improve fire kit removal procedures. There is certainly experience in emergency service workers in the safe donning and doffing of PPE for chemical or nuclear exposure. Research should be carried out to examine the best means of removing fire kit and in which order to ensure contamination is kept to a minimum.

Structural design issues within fire stations were also highlighted as part of this review to reduce exposure to PAHs. A number of international studies identified building age and design as a factor. From these studies there needs to be a better separation of engine and equipment bays from office and domestic areas. Ventilation equipment is also available for use when engines are started, but this may not always be used effectively.

17 Phase 3: Conclusions

Polyaromatic hydrocarbons exist in most indoor and outdoor environments and are produced through incomplete combustion of organic materials. Concern has been raised with firefighters who have been found to be at increased risk of a number of cancers including melanoma. A number of conclusions have been made as a result of this project.

- This study confirms that firefighters are exposed to a variety of PAHs during live firefighting (both urban and wildland), during training exercises, overhaul and within fire stations.
- Identification of PAHs within fire stations highlights the need to consider the structural design of fire stations as well as ventilation requirements.
- Methods of donning and doffing of fire kit and cleaning of fire kit also warrants discussion where it is suggested that fire kit be washed after every fire event; this is likely to vary by country

Further research on this topic could provide additional data to assist in understanding the role of PAHs on the occurrence of cancer among firefighters. Research questions could include:

- What are the causes of the highest exposures to PAHs in fires under different scenarios (e.g. fire from a cigarette on a sofa, wild fires, external waste bin fires etc)?
- What is the relative potency of different PAHs in relation to cancer occurrence?
- What is the potential role and efficacy of biomonitoring of firefighters to assess exposure to PAHs in the course of their work?
- What are the current science/recommendations within the fire fighter safety industry and governmental occupational agencies and how protective are they to firefighters? What is identified good practice within the industry?
- What is the effect of changes in fire station design, ventilation and practices regarding storage/accessibility of fire tenders on exposures to firefighters within the stations?

18 Phase 3: References

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Appendix 4. Summary of PAH Exposures

Table A1: Summary of PAH Exposures

Author	Setting	Measurement	Method	Concentration
Fent et al., (2013)	USA Two controlled burns	Personal air sampling	SKC XAD-2 OVS sorbent tubes with built in glass fibre filter Analysis: NIOSH method 5506	Round 1: n=14, median 4,700 range 750 – 22,000 μg/m^3 Round 2: n=13, median 1,200 range 61 – 2,200 μg/m^3
		Dermal sampling Pre and post sampling of forearms, hands, neck, face	Method: cloth wipes (Texwipe® AlphaWipes®) using corn oil as wetting agent Analysis: NIOSH Method 5506	Most PAH levels below minimum detectable concentration Median post exposure neck > face > hand ≈ arm Change in PAH levels neck (post minus pre) Round 1 n=15, median 12, range -2.8-150 μg/m^2 Round 2 n=14, median 11, range -38-61 μg/m^2
		Surface sampling Pre and post sampling of turnout gear sleeves	Method: Allegro® 70% isopropyl alcohol wipes Analysis: NIOSH Method 5506	Round 1 Pre-burn, n=15, median 2.5 μg Post-burn, n=15, median 1.9 μg Round 2 Pre-burn, n=15, median 1.2 μg Post-burn, n=15, median 0.61 μg

Author	Setting	Measurement	Method	Concentration
Fent et al., (2017)	USA Four controlled residential fires	Dermal sampling Pre and post sampling of hands and neck	Method: cloth wipes (TX1009, Texwipe) using corn oil as wetting agent Analysis: HPLC/UV/FL (NIOSH Method 5506)	Hands: Pre-fire, n=12, median <4.5, IQR <4.5 µg/m^2 Post-fire, n=142, median 16.3, IQR 5.3-125 µg/m^2 Neck: Pre-fire, n=12, median <24, IQR <24-31.2 µg/m^2 Post-fire, n=124, median <24, IQR <24-38.1 µg/m^2
Fernando et al., (2016)	Canada Five training exercises in burn houses to wood smoke	Personal air sampling ~ 30 min	Method: XAD-2 tube, active sampling Analysis: GC-MSD	n=26, average (SD) 280 (190) µg/m^3
		Dermal sampling: Pre and post sampling of wrist, neck, forehead, back, fingers	Method: alcohol (2-propanol) wipes Analysis: GC-MSD	n=28 (firefighters) Average four-fold increase in concentrations post-exposure
Stec et al., (2018)	UK Two training exercises in a shipping container lasting ~ 60 min	Dermal sampling: Pre and post exposure wipes from back and front of neck, jawline and hands)	Method: wipe samples Full details of sampling and analytical methods given in supplementary material	n=4 each location Significant increases in the majority of PAHs measured post-exposure, especially hands
		PPE samples: exterior of gloves, jacket zipper, cover, shoulder of tunic, flash hood, exterior of SCBA mask	Method: wipe samples	n=4 each PPE sample Generally higher concentrations in the majority of PAHs measured post-exposure

Author	Setting	Measurement	Method	Concentration
			Full details of sampling and analytical methods given in supplementary material	
Robinson et al., (2008)	USA Five prescribed pile burns of pine trees	Personal air sampling during ignition/flaming (5 burns) 8 hr; Area sampling during ignition/flaming and smouldering (both 2 burns) 3 hr	Method: Personal – active sampling onto a PTFE filter using a 37 mm polystyrene cassette Area – quartz filters attached to US EPA approved speciation sampler (PM2.5) Analysis: Personal – Aerotech Environmental Laboratories Area – GC-MS	Individual PAHs measured, n=12 Three of 16 PAHs increased post exposure – naphthalene, fluorene and phenanthrene Area samples: Ignition/smouldering – n=2, 0.61 and 3.65 µg/m^3 Smouldering – n=2, 0.86 and 3.38 µg/m^3
Navarro et al., (2017)	USA Two wildland fires Two training fires	Personal air sampling	Method: XAD-2 sorbent tube and 37 mm closed phase cassette with quartz filters impregnated with XAD-4 Analysis: GC-MSD	Prescribed fires: n=10, GM (GSD) 265 (3), range <39-9103 ng/m^3 Wildfires: n=28, GM (GSD) 586 (3), range 88-7935 ng/m^3
Baxter et al., (2014)	USA 5 fire overhaul events 2 firehouses: kitchen; truck bay; sleeping quarters	Area sampling in firehouses 8 hr Personal and area air sampling overhaul events 15-29 min	Method: Filter cassette with 37 mm Teflon filter followed by an XAD-2 sorbent tube Analysis: NIOSH method 5515	Firehouse A: Only naphthalene detected - kitchen 9.22 µg/m^3, truck bay 9.22 µg/m^3, Sleeping quarters below limit of quantification (BLQ) Firehouse B, Control environment: all PAH BLQ

Author	Setting	Measurement	Method	Concentration
	Control environment (radiation safety office): break room; office Five live overhaul events			Overhaul events, personal samples: Naphthalalene – n=2, range 26, 57 µg/m^3 Acenaphthylene – n=2, range BLQ, 3.6 µg/m^3 Benzofluoranthene – n=2, range 13, 23 µg/m^3 Overhaul events, area samples: Naphthalalene – n=6, range 2-90 µg/m^3 Acenaphthylene – n=6, range BLQ – 8.0 µg/m^3 Benzofluoranthene – n=6, range BLQ – 23 µg/m^3
		Personal dermal sampling (face and neck) collected after fire events	Method: face and neck wipes (Wet-nap) Analysis: NIOSH method 5515	Ten PAHs detected in skin samples
Oliveira et al., (2016)	Portugal 8 fire stations	Personal air sampling 4 hr	Method: Gilian, models GilAir3 and ProValue3; Sensidyne, USA, with PTFE filter Analysis: liquid chromatography	Firestation: n, Median, range (ng/m^3) MRD: 9, 229, 200-296 TDC: 12, 46.4, 44.0-49.4 SDM: 6, 91.7, 64.5-124 MDL: 9, 256, 77.6-352 TMC: 9, 51.1, 48.8-57.5 VNH: 12, 74.6, 44.4-125 BRG: 12, 55.0, 49.8-137

Author	Setting	Measurement	Method	Concentration
				FEC: 12, 428, 250-631
Sparer et al., (2017)	USA 4 fire stations: truck bay; outside; kitchen	Area air sampling 4 hr	Method/analysis: continuous monitoring (1 min intervals) using Ecochem PAS 2000CE	Station: n, average (SD) (ng/m^3) **Outside** 1: 8, 32.25 (10.72) 2: 7, 11.98 (4.28) 3: 6, 5.03 (1.76) 4: 5, 68.3 (42.25) **Outside** 1: 8, 4.92 (1.24) 2: 7, 5.20 (3.63) 3: 6, 2.55 (0.26) 4: 5, 2.07 (0.78) **Kitchen** 1: 8, 10.84 (1.78) 2: 7, 9.81 (1.78) 4: 5, 1.69 (0.60)
Bott et al., (2017)	Australia 8 fire stations: engine bay; duty office;	Area air sampling 10 hr	Method: glass tube with Tenax sandwiched between polyurethane foam	Range (μg/m^3) Engine bay: n=9, 0.1 > instrument maximum (1 μg/m^3)

Author	Setting	Measurement	Method	Concentration
	dormitory; outside fire station		Analysis: EPA method TO-13A	Duty office: n=8, 0.1 – 0.6 Dormitories: n=8, 0.1 – 0.9 Outside measurements: n=8, <0.2 µg/m^3

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